FINAL REPORT

DEGRADATION EFFECTS ON MOTOR VEHICLE EXHAUST EMISSION

PREPARED UNDER CONTRACTS
ARB 3-199 AND 3-584

WITH

STATE OF CALIFORNIA
AIR RESOURCES BOARD

MARCH 1976

BY

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President

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"The statements and conclusions in this report are those of the Contractor and not necessarily those of the State Air Resources Board. The mention of commercial products, their source of their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products."

ABSTRACT

A total of 600 (1968 to 1974) randomly selected vehicles were screened by engine parameter, safety, and idle tests. Those cars requiring major engine repairs or safety defects were rejected. Five hundred and seventy-six (576) vehicles were selected for testing and incorporated into four test groups. Each group contained 144 vehicles and were designated as the Baseline Control Group (Group I), the Inspection Group (Group II), a Manufacturer's Specification Group (Group III), and a Mandatory Maintenance and Parameter Inspection Group (Group IV).

All vehicles entering the test program received a baseline 1972 Federal CVS emission test, followed by a hot-idle test (low and 2,500 rpm). Adjustment or repair of vehicles was accomplished by Olson Laboratories for Group II and Group III vehicles. Class A garages performed maintenance on Group IV vehicles. Following the necessary maintenance, the Federal and idle tests were repeated for Group II, Group III, and Group IV vehicles. All vehicles in these groups were retested at 1- 2- 6- 9- and 12-month intervals. This report documents the results of the test program.

"This report was submitted in fulfillment of ARB 3-199 and ARB 3-584 by Olson Laboratories, Inc., under the sponsorship of the California Air Resources Board."

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Section 1

INTRODUCTION

This report for the Degradation Effects on Motor Vehicle Exhaust Emission describes the conduct of the study, and provides the findings, results, and conclusions of the analyses.

1.1 STATEMENT OF THE PROBLEM

Numerous studies have been conducted to determine the factors that influence vehicle emissions. Based on these investigations and the institution of both State and Federal regulations, manufacturers are developing and producing vehicles with exhausts that are becoming increasingly "cleaner" with each newer model-year vehicle. However, a significant problem still remains to be resolved. As both the controlled and uncontrolled vehicles accumulate time and mileage, deterioration of vehicle emissions may occur.

Studies conducted by governmental agencies and the automotive industry have shown that corrective maintenance and adjustments can reduce rising emission levels. Many feel that a vehicle emission inspection program, that would identify those vehicles requiring corrective maintenance and adjustments, could become an effective first step in reducing exhaust pollutants.

There are many different inspection schemes, each purported to be the best for a Statewide program. The final effectiveness, however, is a function of the type of maintenance which would be triggered by an inspection. In this program, the California Air Resources Board (CARB) identified four levels of maintenance to be investigated. These maintenance regimes range from a minimum of uncontrolled maintenance to a maximum of engine maintenance under direct control of the project personnel.

1.2 STUDY PURPOSE

In evaluating various control strategies for mobile source emissions, regulatory agencies had to make unsupported assumptions concerning the degree of deterioration in the emission characteristics of in-use vehicles. This has caused uncertainties in the long-term effectiveness of periodic vehicle inspection and maintenance programs. Attempts to use data from previous studies such as the CARB-Northrop study (Reference 1) and the APRAC-CAPE 13 study (Reference 2) to evaluate degradation effects have been largely unsuccessful because these studies were not designed to provide such information with adequate sensitivity and resolution.

It is generally agreed that recently tuned vehicles will have lower exhaust emissions, and that exhaust emissions will remain low for some period of time. Engine performance will then begin to decay gradually until some critical point at which one or a combination of factors cause emission deterioration. As this higher emission level is reached, the deterioration will continue to a point where the vehicle has noticeably poor performance as discerned by its owner. At this time, another tune-up would be performed. This tune-up due to poor performance will occur typically at 15,000- to 20,000-mile intervals, or approximately every 18 months. Because of deposit effects, plus wear to engine components such as intake and exhaust valves, cylinder walls and piston rings, the original minimum exhaust emission level ordinarily cannot be achieved when the car is tuned up.

Although the general sequence of events leading to exhaust emission deterioration can be described, it is known that individual automobiles vary widely in the time, the cause, and the ultimate degree of deterioration. Futhermore, the degree of emission degradation will be greatly affected by the attitude and practices of the individual owner with respect to use and maintenance of his vehicle.

As documented in the CARB-Northrop report, the technical and economic feasibility of instituting Statewide inspection facilities were shown to be cost-effective. Within certain cost constraints, public acceptability of mandatory periodic emission inspection was determined to be favorable. However, the feasibility of a periodic inspection or maintenance program must consider the degradation effects during the period between adjustments or repairs. This report describes the test program in which quantitative data were collected and analyzed to determine the effects of vehicle degradation and maintenance on exhaust emission control programs.

The deterioration data acquired in this effort may be applied to refine the evaluation of the effectiveness of a periodic vehicle inspection program and to evaluate deterioration effects on an emission control program based on mandatory maintenance. The results will provide additional guidelines for any emission control program considered for Statewide implementation.

Section 2

TEST PROGRAM DESCRIPTION

2.1 BACKGROUND

2.1.1 Effect of Automobile Emission on Air Quality

Since the early 1950's, the automobile has been identified as a factor in the deterioration of air quality in California. High atmospheric concentrations of carbon monoxide (CO), reactive hydrocarbons (HC), oxides of nitrogen (NO_x), and particulate matter (PM) are, in large part, directly attributable to automobile exhaust.

Additional large quantities of HC are emitted by evaporation from automobiles and from the operation of filling stations. The production of photochemical smog by the atmospheric reaction of HC and NO_x, under the influence of solar irradiation, has been investigated and documented by Haagen-Smit and others (References 3 and 4).

The emission of air contaminants is a basic characteristic of the modern internal combustion engine. However, the amount of pollutants emitted per mile of operation can vary widely, depending on engine design factors and on conditions of operation. Proper understanding and application of these factors can result in a significant reduction of pollutant emissions by cars. Added equipment can be installed on automobile engines to further reduce the quantity of pollutants emitted.

All three approaches have been applied to the reduction of harmful exhaust emissions. To meet increasingly more stringent standards, automobile manufacturers have installed emission control devices on existing engines, revised recommended engine operating parameters, and redesigned basic engine characteristics.

Modification of engine operating parameters, including idle speed, air-fuel ratio and spark timing can all affect the concentration of pollutants in exhaust gases from normal engines. The objective of modifying these engine parameters is to optimize the engine operation with respect to exhaust emissions. Unfortunately, when HC and CO are minimized, NO_x emissions may increase. (However, when air-fuel ratios exceed stoichiometric, NO_x formation actually decreases.) When adjustments are made which optimize engine performance with respect to emissions, the vehicle performance, such as acceleration and driveability, may be degraded with respect to generally acceptable standards.

2.1.2 Emission Control Techniques

Early attempts at vehicle emission control included the mandatory installation of crankcase controls on all new cars sold in California beginning in 1963. (The automobile manufacturers voluntarily installed these devices on California cars beginning in 1961.) The desired result of this action was to materially reduce the amount of HC emitted through the crankcase vent.

To further reduce HC emissions, all 1970 and subsequent model cars sold in California have been equipped with devices to reduce evaporative emissions. The most common of these are activated carbon filters which absorb HC vapors from the fuel tank and carburetor until they are purged into the intake system during certain modes of operation.

A large part of the HC emissions and all of the CO and NO_x produced by the automobile engine are emitted in the exhaust gases. The control of exhaust emissions has been accomplished for new automobiles by establishing standards and prescribing test procedures to evaluate these exhaust emissions. The various automobile manufacturers have defined and developed the methods to meet the standards.

Exhaust emission standards for CO and HC became effective in California with the 1966 model-year domestic vehicles. To meet these initial emission standards, the automobile manufacturers took one of two approaches. Of the major U.S. manufacturers, only Chrysler, incorporated engine modifications which resulted in leaner air-fuel ratios during idle- and low-speed cruise and during engine warmup. Spark timing was retarded to assure ignition of these leaner mixtures. The spark timing was automatically advanced during closed throttle deceleration to lengthen combustion time. The ability of the Chrysler engines to meet the more stringent 1966 and subsequent standards, depends, among other things, on careful adjustment of the carburetor and ignition system and on the proper functioning of the distributor vacuum control valve.

To meet 1966 standards, the other major domestic manufacturers installed an air pump which provided air for more complete combustion of the hot exhaust gases as they left the engine cylinders. This resulted in more complete oxidation of CO and HC. Other adjustments on the air-injection-equipped cars included a modified spark advance schedule, increased idling speed, and an intake manifold relief valve which prevented backfiring during closed throttle decelerations. The air-injection system was used on most car models for only 1 or 2 years.

Improvements in engine control systems and in engine design have subsequently resulted in better emission control and improved reliability on all domestic and foreign cars. Additional design improvements included redesigned combustion chambers and air-intake systems. Better controls included tighter manufacturing and adjustment tolerances on carburetors, and optimizing spark advance control to obtain low emissions.

Although the Federal government has specifically preempted the authority to set emission standards for new vehicles, a special waiver provision permits the State of California to establish and enforce more restrictive standards and procedures than the national standards. California established standards for NO_x; beginning with the 1971 models, becoming more stringent in 1972, and still more stringent in 1974. The California standards for 1975 are also more strict than existing Federal standards.

2.2 STUDY OBJECTIVES

The criteria and standards established for automobile exhaust emissions have been applied mainly to automobiles at the time of initial manufacture or subsequent transfer of title. Except for apprehension of flagrant smoke emitters and the recent California Highway Patrol random roadside inspection program, little effort has been expended to ensure continued performance of emission control systems. All cars which initially meet the standards, deteriorate in performance during their lifetime. This may be due either to wear or to deliberate maladjustment of engine performance parameters by the owners.

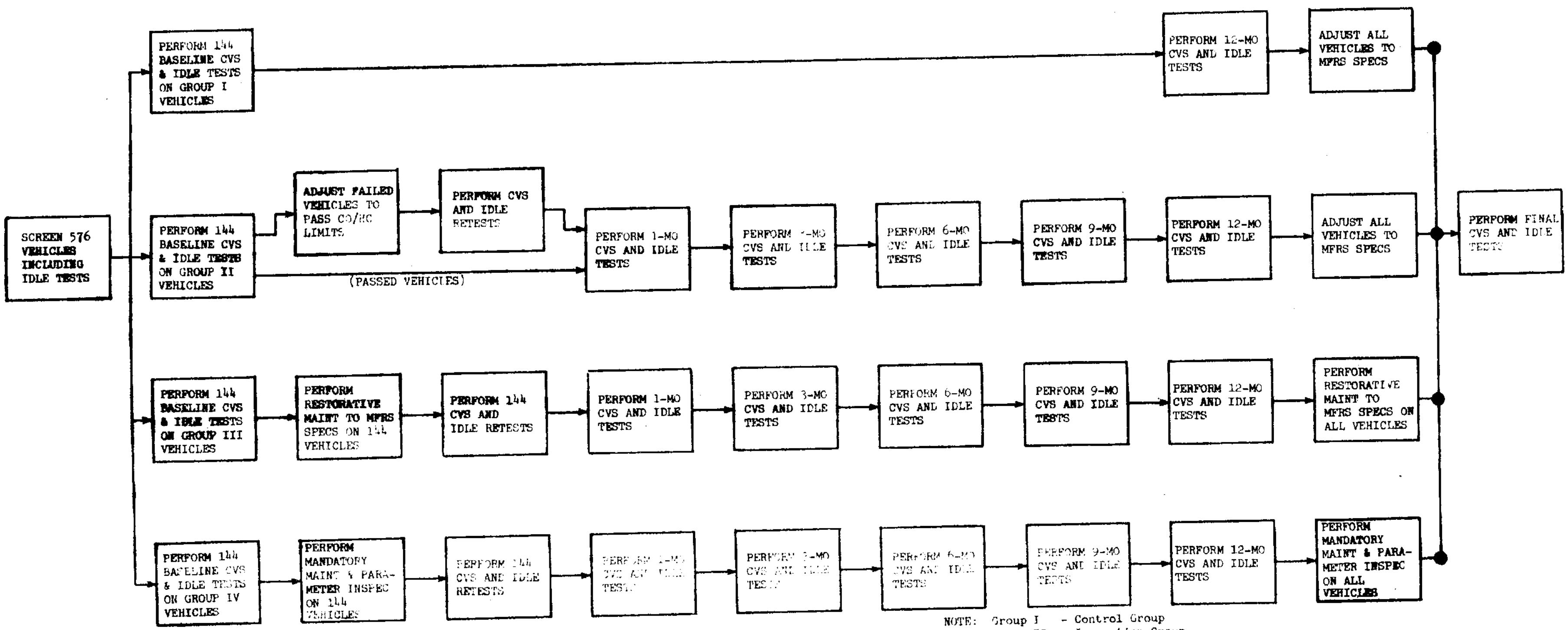
Studies already completed show that acceptable emission performance for most cars can be achieved and sustained by proper maintenance and repair (References 5 and 6). The maintenance work must be emission-reduction oriented to achieve the desired results; indicating a necessity for established standards of training and experience for the mechanics.

The results of all studies examined may be summarized in two points. First, the incorporation of emission controls on cars does not ensure continued low emissions. The control systems tend to deteriorate in their performance. Second, with proper maintenance and adjustments, vehicles will operate with lower emission levels. Therefore, the primary objectives of this program were: 1) determine the effectiveness of an inspection/maintenance program and a mandatory maintenance program considering the degradation factors associated with each, 2) determine the rate of exhaust degradation in the California population if no inspection or maintenance program is instituted, and 3) compile the above information on a vehicle sample representative of the January 1975 vehicle population.

2.3 MAINTENANCE REGIMES DEFINITIONS

Four similar groups of 1968 to 1974 exhaust emission controlled vehicles were randomly selected according to projected figures representative of the January 1975 vehicle population. Each of the four groups contained 144 vehicles. Prior to entering the test program, each vehicle was screened to ensure that no major engine or safety defect existed. The screening process included both a visual inspection and idle emission test for CO and HC.

All test vehicles were subjected to 1972 Federal CVS cold-start, followed by hot idle (low and high rpm) emission tests. Three of the four groups received specific maintenance during the 12 months of the test program. An overview of the test program is illustrated in Figure 2-1.



NOTE: Group I - Control Group
Group II - Inspection Group
Group III - Manufacturer's Specification Group
Group IV - Mandatory Maintenance & Parameter Inspection Group

FIGURE 2-1. TEST PROGRAM OVERVIEW

The four groups consisted of a control group, an inspection group, a manufacturer's specification group, and a mandatory maintenance and parameter inspection group. Detailed descriptions of the control group and the three various levels of maintenance groups follow.

2.3.1 Control Group

The control group (Group I) consisted of 144 vehicles which provided information with respect to emission degradation of the current population as they now exist. In order to minimize any bias of the sample with respect to owner-controlled maintenance, vehicle owners were given minimum information about the test program. Consequently, the vehicles were brought in for testing only at 0- and 12-month intervals. Maintenance records were requested at the 12-month interval to document any repair actions and attendant costs.

The only maintenance performed by Olson was the repair after the 12-month test. Vehicle owners were responsible for their respective vehicle's maintenance during the 12-month period.

2.3.2 Inspection Group

The inspection group (Group II) also consisted of a 144-vehicle sample. In this idle inspection and maintenance regime, a sample of the exhaust gas was taken and analyzed for HC and CO while the vehicle was operating at idle. If the vehicle failed the idle standards shown in Table 2-1, the vehicle was given only that adjustment and/or repair required to pass the emission standard.

Vehicles were tested at 0-, 1-, 3-, 6-, 9-, and 12-month intervals. All maintenance performed at the beginning (0-month) and end (12-month) on these vehicles was

Table 2-1. DEGRADATION TESTING
50% PASS/FAIL IDLE LIMITS

	HC ppm	CO%
1968-1969		
Air Injection	325	3.0
Engine Modification	350	3.0
Exempt (NO, NO_x Retrofit)		
AI	400	4.0
EM	450	4.5
Below 140 CID		
AI	350	3.5
EM	400	3.5
Exempt below 140 CID		
AI	450	3.5
EM	500	5.0
1970-1971		
70 NO_x Retrofit/AI and EM	300	3.0
70 Exempt/AI and EM	350	3.5
70 Below 140 CID (with) AI and EM	350	3.5
70 Exempt below 140 CID/AI and EM	400	4.0
71 AI and EM	275	3.0
71 Below 140 CID AI and EM	350	3.0
1972-1974		
AI	250	2.0
EM	300	2.5
Below 140 CID		
AI	300	2.5
EM	350	2.5

11 October 1973

carried out by Olson Laboratories personnel. As was the case of the control group, vehicle owners were responsible for any maintenance during the 12-month period.

2.3.3 Manufacturer's Specification Group

The manufacturer's specification group (Group III) included an additional 144 vehicles. Each vehicle was subjected to restorative maintenance after the baseline test. The restorative maintenance consisted of an inspection, repair or replacement of each vehicle's engine and emission control devices to meet the original performance condition. The items inspected included those listed in the manufacturer's maintenance manuals. Vehicles were tested at 0-, 1-, 3-, 6-, 9-, and 12-month intervals. All maintenance performed on these vehicles was carried out and documented by Olson personnel. Vehicle owners were instructed to bring their vehicle to Olson for all scheduled and unscheduled maintenance.

2.3.4 Mandatory Maintenance and Parameter Inspection Group

The mandatory maintenance and parameter inspection group (Group IV) included the final 144 vehicles. Each vehicle was subjected to maintenance after the baseline test. The maintenance consisted of mandatory replacement of spark plugs, points, rotor, condenser, air filter, and PCV valve. The parameter inspection consisted of diagnosis and replacement of other engine and emission control devices to meet the original performance condition. Vehicles were tested at 0-, 1-, 3-, 6-, 9-, and 12-month intervals. All maintenance on these vehicles were performed by Class A mechanics in the private repair sector. Vehicle owners were asked to keep accurate maintenance records throughout the 12-month period and were responsible for any maintenance performed.

2.4 EXPERIMENT DESIGN

The test program was devised to obtain empirical data on vehicle emission inspection and maintenance and degradation over a period of 12 months. The study commenced on 7 September 1973, scheduled and contracted for completion within 27 months. To obtain statistically valid data, carefully conceived experiment design was developed prior to the commencement of vehicle testing. Discussed below are the considerations that went into designing the experiment, gathering the test data, and analyzing the information obtained.

2.4.1 Hypothesis Testing

The purpose of this study is to compare the relative merits of the three maintenance regimes in reducing vehicle emissions of HC, CO, and NO_x. In statistical terminology, the intent is to test the following hypotheses:

a. There is no difference between test results on the total population before and after vehicle maintenance service.

b. There is no difference in emission reductions achievable by each of the three maintenance regimes.

c. There is no difference in emission degradation for each of the three maintenance regimes.

Hypothesis a., above, states that vehicle maintenance, if required, will not affect emission levels. Hypothesis b., states that if reductions are realizable, they will be the same for each pollutant, regardless of maintenance regime. Hypothesis c., states that the degradation will be the same for each pollutant, regardless of the maintenance regime. Very likely, there will be differences and the experiment was designed to identify and quantify these differences.

2.4.2 Experiment Design

The testing pattern chosen was structured to have an equal number of cars for each group. The structure assures that a representative cross-section of the vehicle population, based on age, make, and model, is exposed to each type of test. Importantly, the matching of individual vehicles to test and maintenance should be purely random.

The 144-vehicle sample for each group shown in Table 2-2 is representative of the Statewide population of privately-owned passenger automobiles under 6,001 pounds gross weight for the 1968 through 1974 model-year vintage. Selection is based on registration data provided by Rueben H. Donnelly Corporation, one of two firms who have access to the California Department of Motor Vehicles registration data. The resulting distribution is based on the population projected for the beginning of January 1975.

2.5 OPERATIONAL PROCEDURES AND DATA TREATMENT

In the following paragraphs, the vehicle emission testing and maintenance procedures are described. In addition, the data treatment process is also described.

2.5.1 Emission Test Procedures

After candidate vehicles were identified, they were scheduled into the Olson test facility for a preliminary

Table 2-2. VEHICLE TEST FLEET FOR EACH GROUP

Classification	1968 % of Year Total	1968 No. in Sample	1969 % of Year Total	1969 No. in Sample	1970 % of Year Total	1970 No. in Sample	1971 % of Year Total	1971 No. in Sample	1972 % of Year Total	1972 No. in Sample	1973 % of Year Total	1973 No. in Sample	1974 No. in Sample	Total
Luxury	6	1	6	1	5	1	4	1	4	1	5	1	1	7
Standard	34	6	35	7	28	6	20	4	20	5	25	5	3	34
Intermediate	14	3	12	3	12	2	8	2	10	2	11	3	5	20
Compact	17	3	23	4	24	4	21	4	22	4	19	5	5	29
Subcompact /Imports	29	5	24	4	31	6	47	10	44	10	40	8	9	52
Total	100%	18	100%	19	100%	19	100%	21	100%	22	100%	22	23	144

screening inspection. Engine condition was analyzed, followed by a check of the exhaust system, the brake system, and other safety-related items. Vehicles that required major engine repair were eliminated from the program. Vehicles that exhibited such defects as faulty brakes, exhaust system or tires were rejected on the basis of laboratory safety requirements, with the vehicle owner given the option to repair these defects in order to be accepted in the program.

Of the 600 vehicles which were screened, 576 passed the screening inspection, received a 1972 Federal CVS Emission Test followed by an idle test. These baseline tests provide a reference point for comparison with emission levels throughout the program.

Vehicles were assigned to the respective maintenance groups. Distribution of vehicles in all four groups were based on the screening idle test to assure an approximately equal number of both high and low emitters in each group.

All vehicles subjected to initial adjustments or repairs were, again, processed through the test cycle of a 1972 Federal CVS test followed by another idle emission test, and then were returned to the vehicle owner. Vehicles were rescheduled in at the prescribed test intervals during the 12-month test period.

In a program of this type, the ideal condition would be to test all vehicles simultaneously. Obviously this could not be done. In this test program, a complete test cycle for all cars required approximately 3 months. The initial testing mixed all classes to assure that any seasonal effects were cancelled. Each retest was scheduled at the proper interval for that specific car in order to maintain validity of the time-based analysis.

It should be noted that Group IV was an amendment to the contract and did not start until June 6, 1974.

Therefore, there is about 7 months' shift in the test data for Group IV.

Indolene 30 test fuel was used throughout the entire program to eliminate the effect of seasonal fuel volatility and composition variables on the precision of exhaust emission measurements. This also assured maximum accuracy in the computed fuel consumption values. Although the average C/H ratio differences in tank fuel would not have a great effect on the measurements, past programs have shown that seasonal volatility changes in gasoline can significantly change the emissions, especially on newer automobiles. Use of the Indolene test fuel eliminated this variable from this program.

2.5.2 Routine System Calibration and Quality Assurance Procedures

In order to ensure the validity of the data, a series of routine calibration procedures and quality assurance checks were conducted throughout the test program as shown in the Calibration Schedule, Table 2-3.

Test instrumentation used was calibrated periodically throughout the test program. Checks of zero and span levels were made prior to each test. In addition, Olson provided a quality control specialist to check operational procedures and the reasonableness of the data being obtained. The following paragraphs describe the quality assurance procedures used throughout the test program.

2.5.2.1 Ambient Conditions

Wet and dry bulb temperatures in the laboratory area were continuously measured and recorded on a strip chart recorder. Olson uses a continuous system in which

Table 2-3. CALIBRATION SCHEDULE

EQUIPMENT	INITIAL C/O	MONTHLY	WEEKLY	DAILY	PER TEST
Constant Volume Sampler					
1. Calibrate CVS pump	X				
2. Obtain two valid propane recovery test	X	X	X	X	
3. Perform leak test	X	X	X	X	
Dynamometer					
1. Calibrate actual vs. indicated hp for each inertia weight	X				
2. Calibrate actual vs. indicated hp for two inertia weight	X	X			
3. Calibrate torque bridge	X				
4. Calibrate speed and load meter	X	X			
Instrument System					
1. Calibrate instruments with with EPA-named gases	X	X	X		
2. Perform curve fit for all instrument	X	X	X		
3. Perform system leak test	X	X	X	X	
4. Calibrate temperature recorders	X	X			
5. Calibrate driver's aid					
• speed vs. time	X	X			
• 0 and 50 mph	X	X	X	X	X
6. Calibrate instruments with "working" span gases (pre and post test cal.)	X	X	X	X	X

thermistors are installed in a forced-airflow, wet and dry bulb temperature measurement device. Prior to use, the continuous trace temperature recorders were calibrated with mercury thermometer readings.

The continuous trace records were identified with each of the bag samples to be analyzed. The average wet and dry bulb temperatures for each bag were used for the gaseous emission calculations for each portion of the test cycle. This system also verifies that the laboratory test temperature was maintained between 68^{o} and $86^{o}F$.

A second temperature monitoring/recording system was installed in the cold-soak area of the facility. This served as a verification that the prescribed cold-soak conditions were maintained.

Barometric pressure was measured using a laboratory standard mercury barometer which was corrected for ambient temperature.

2.5.2.2 Emissions Testing Equipment

Dynamometer

The dynamometer was calibrated for each inertia weight (1,750 through 5,500 pounds), using the coast-down method to determine indicated-versus-actual horsepower. On a monthly basis, two inertia weights were calibrated; and if the actual horsepower varied more than ±1 horsepower, the entire calibration was repeated for each inertia weight. Dynamometer speed and power meter calibration were performed on a monthly basis or when any maintenance was performed on the dynamometer.

CVS System

The CVS pump was calibrated at a minimum of 6-month intervals using a Meriam laminar flow element. The calibration of the laminar flow element is traceable to the National Bureau of Standards. The CVS was checked daily by metering up to 20 grams of instrument-grade propane into the sampler. A sample form of the daily propane test log is shown in Table 2-4. In the event the propane recovery is not within ±2 percent, measured in the upper one-third of the 0 to 300 ppm/C range, the cause was determined and fixed. Two successive successfull propane recovery tests were then performed prior to resumption of testing. Any major repair of the pump was automatically followed by a full laminar flow calibration prior to the resumption of testing.

Analytical Systems

The analytical system used on this program was a Scott 119 system. A complete curve check of the analytical system was performed weekly.

Figure 2-2 is an example of the daily checks made on the system. This routine check, prior to initiating testing on a daily basis, includes a leak check. It provides a running log of system performance and was used to ensure that each instrument and the system is in condition to yield accurate emissions data.

In addition to these two daily logs, Olson has maintenance logs on each instrument and system in which all maintenance, both preventive and repair, was logged at the time of the maintenance action.

NO_x Converter Efficiency

The efficiency of the chemiluminescence converter was checked on a daily basis in accordance with the requirements of the Federal Register, Vol. 38, No. 124, June 28, 1973.

Table 2-4. PROPANE INJECTION TEST

Date:____________ CVS Frame #____________ PIP____________ AM

Train #____________ Dept. #____________ Time____________ PM

I. Calculation of V_{mix} (Total Volume of Mixture)

A. P_B = Barom. Pres. = ________ In. Hg x 25.4 = ________ mm Hg

B. P_I = Pump Inlet Dpr = ________ In. H_2O x 1.868 = ________ mm Hg

C. P_p = Pump Inlet Pres. = $P_B - P_I$ = ________ mm Hg

D. P_O = Pump Outlet Pres. = ________ In. H_2O ΔP = ________ In. H_2O

E. T_p = Pump Inlet Temp. = ________ $^oF + 460^oF$ = ________ ^oR

F. $P_p \div T_p$ = ________

G. N = Pump Revs = ________ Time = ________ min; RPM = ________

H. V_O = Pump Vol. per Rev = ________ ft 3/rev

I. $V_{mix} = \frac{P_p}{T_p} \times N \times V_O \times .69474$ = ________ ft^3

II. A. Weight Exp. B. Bag Analysis

Cylinder (gms)		Bag	Deflection	Range	Concentration (ppm)
Before =	______	Sample	______	______	______
After =	______	Bkgd	______	______	______
Δ =	______			Conc =	______

III. Mass Calculation (Mass = $V_{mix} \times 17.3 \times \text{Conc} \times 10^{-6}$)

Mass = ________ gms

$$\text{Error} = \frac{\Delta\text{-Mass}}{\Delta} \times 100 = \_\_\_\_\_ \% \ \text{H/L}$$

COMMENTS:________________________

QC Use

Approved________

Rejected________

By________

Figure 2-2. MASS START-UP CHECK SHEET

DEPT NO	SHIFT	TRAIN	DATE	P.I.C.

CALIBRATION

		HIGH								INTERMEDIATE						
	RNG	GAIN	ZERO	CYCL NO	CONC	DEFL	PRESS	TUNE	GAIN	ZERO	CYL NO	CONC	DEFL	PRESS	MFGRS MODEL NO
CO	750														
	0.3														
FIA	100														
	300														
	IK														
NO_x	100														
	250														
	IK														
CO_2	4.0														
ZERO															

RECORDER				PRESSURE					BY PASS	CONV	REACTOR	LEAK CHECK				
CHART SP	ZERO	GAIN	DVM CORR		SAMPLE	FUEL	AIR	OZONE	FLOW RT	IND TEMP	OPR PRESS		FIA	CO	CO_2	NO_x
				FIA								FL MTR OBS				
				NO_x						°C	MM	MAG OBS				

CVS

1 MIN COUNT	IN PRESS	Δ P	T.P. PRESS	VOL/REV	FLEX	ADAP	BAGS	LIGHTS	PUMPS	SWITCHES	TEMP CONTROL

COMMENTS

Driver's Aid

Olson used a computer-generated driver's aid which generates the 1972 FTP speed/time cycles trace. Standard practice is to calibrate at 0 and 50 mph before and after each test.

2.5.3 Maintenance Procedures

2.5.3.1 Inspection Group

For those vehicles which failed the idle emission standards, only that adjustment and/or repair required to pass the standard was performed. This repair regime should represent the present situation in those states using an idle test inspection program. Standard diagnostic equipment was used when repair was required.

All maintenance which was required during the conduct of the test program was only owner-initiated, and maintenance records were obtained from vehicle owner at the end of the test program.

2.5.3.2 Manufacturer's Specification Group

The manufacturer's specification group (Group III) (all 144 vehicles) were subjected to restorative maintenance after the baseline test. Restorative maintenance consisted of inspection and repair or replacement of each vehicle's engine and emission control devices, to meet the original performance condition. The items inspected included those listed in the manufacturer's maintenance manuals. The specifications contained in the manuals were referred to in determining the required component and/or system condition.

The following procedures were used to determine the actual condition of air filters, ignition systems, PCV systems, air inlet heaters, vacuum advance systems and exhaust gas recirculation systems (see Table 2-5).

1. Set up car on dynamometer

   a) Attach Autoscan leads and vacuum gauge at distributor with tee.

   b) Assure visibility of timing marks.

2. Build engine rpm to 2,500 to 3,000 for approximately 5 seconds (to clean out carbon). Note: Operating temperature should be normal.

3. Insert exhaust probe into exhaust pipe.

4. Remove air cleaner element.

5. Stabilize engine rmp at 2,500; check HC and CO; record on form.

6. Replace air cleaner element.

7. Repeat Step 5. Note: If CO increases 1.5 percent or more, replace air cleaner element.

8. Check CO at idle and record. Bring to specifications with air/fuel mixture, adjust screw and record.

9. Run car at 60 mph fully loaded at wide-open throttle. Check and record dwell, spark plug fouling, secondary wiring, and point opening and closing.

Table 2-5. GROUP III MAINTENANCE

Replacements - Mileage not applicable	
Air Cleaner - Replace	(1) If excessive dirty (2) If soaked (3) If does not pass diagnostic test (4) If height is not correct
PCV - Reject	(1) If excessively oily (2) Clogged (3) If fails diagnostic
Cranckcase Ventilation Filter - Replace	(1) If oily (2) Clogged (3) Not secure in housing
Points - Inspect and Replace	(1) If pitted (2) Worn or oily (3) If fails diagnostic

Mileage Requirements

1. PCV - Replace every 12,000 miles
2. Engine Oil - 6,000 miles or 4 months/replace.
3. Oil Filter - Every other oil change.
4. Auto Trans Fluid - Every 24,000 miles.
5. Coolant - Replace every 24,000 miles.
6. Fuel Filter - Replace every 12,000 miles.
7. Canister Filter - Replace at 24,000 miles
8. Crankcase Vent Filter - Replace at 12,000 miles.

Manufacturer's Maintenance

Other maintenance/replacement (emission related) not listed above will be done as per manufacturer's specifications. If a part has recently been replaced by owner and does not require additional requirements, document this on maintenance form (e.g., plugs ok - replaced recently).

10. Reduce speed to 0 mph and unload dynamometer.

    a) Accelerate steadily to 50 mph.

    b) Check and record VSAD. Note: Transmission-controlled vacuum indicated at high gear shift. Speed-controlled vacuum indicated between 25 and 40 mph. Spark delay run at 2,500 rpm. Record elapsed time to vacuum increase.

    c) Check and record timing.

11. Check PCV with crankcase testing gauge and record condition.

12. Visually check EGR system and record condition.

Accurate maintenance records were kept, and parts and labor costs were segregated. Owners were instructed to do no maintenance on their own, but rather to bring the vehicle to the contractor for any repair and/or adjustment they felt was necessary. This included all maintenance, both corrective and preventive. Participants were informed that no major engine work would be performed (i.e., valves, overhauls, etc.) by the contractor.

2.5.3.3 Mandatory Maintenance and Parameter Inspection Group

Group IV vehicles were subjected to rigorously-controlled Mandatory Maintenance and Parameter Inspection Program. This program was conducted in five typical commercial service organizations (California Class A stations) which were upgraded by the addition of specified diagnostic and emission measurement equipment and whose mechanics received an intensive training program. Following the initial baseline CVS and hot-idle test, each car was subjected to the specified MM-PI procedures. Approximately 29 cars were processed in each upgraded Class A station. These procedures included mandatory replacement of ignition components such as spark plugs, points, rotor and condenser, and of the air cleaner, fuel filter and PCV valves; and mandatory adjustment to manufacturer's specification of idle rpm, idle mixture, dwell and timing.

The parameter inspection portion of the procedure included inspection and replacement, if necessary, of distributor caps, ignition coils and secondary wiring; plus inspection and repair or adjustment of heated air inlet, EGR valves, VSAD systems and other emission control systems or devices. The differences between the manufacturer's specification group and the MM-PI group are shown in Table 2-6. All of the vehicles in this group were subjected to the 1-, 3-, 6-, 9-, and 12-month retest, exactly as the other vehicles in Groups II and III. The owner was instructed not to adjust or maintain the vehicles. If they required any service, they were to return the car to Olson, and the private sector garage which accomplished the initial MM-PI service would perform the work. The required service was accomplished and the upgraded mechanic had the additional responsibility of rechecking the engine parameters which affect emissions and to assure that the engine was operating at the lowest possible level of emission consistent with the desired improvement in performance. In other words, to the extent that the owners desired performance related maintenance, the upgraded industry was encouraged to prevent or retard emission degradation.

Table 2-6. COMPARISON OF MANUFACTURER'S SPECIFICATION AND MM-PI GROUPS

	MANDATORY MAINTENANCE AND PARAMETER INSPECTION	RESTORATIVE MAINTENANCE TO MANUFACTURER'S SPECIFICATION
A. Mandatory Maintenance		
Air filter	Replace	Inspect and replace if necessary
Fuel filter	Replace	No action
PCV System	Replace valve	Inspect and replace if necessary
Ignition System	Replace spark plugs, points, rotor and condenser, adjust timing and dwell to manufacturer's specification	Inspect ignition system with analyzer under loaded test, replace only defective components, adjust timing and dwell to manufacturer's specification
Idle RPM	Mandatory adjust to manufacturer's specification	Check and adjust if necessary to manufacturer's specification
Idle Mixture	Idle emission and test to adjust for minimum CO	Check and adjust if necessary to manufacturer's specification
B. Parameter Inspections		
Ignition System	Inspect distributor cap, ignition coil and ignition wires; replace components which will not last 1 year	Covered above
Emission Control System	Perform functional check, repair as necessary	Perform functional check, repair as necessary
Program Control		
Location of Maintenance	Upgraded certified private service industry	Contractor's test laboratory
Mechanics	Specially trained mechanics and inspectors at Class A stations	Contractor's mechanic
Procedures	Standardized procedures	Standardized procedures

2.5.4 <u>Data Treatment</u>

The exhaust emission levels were obtained in accordance with the 1972 FTP. The exhaust mass emission (grams/mile) HC, CO, CO_2, and NO_x emission levels were calculated in accordance with the Federal Register. The NO_x emission level was corrected for humidity.

Fuel economy was calculated using exhaust emissions and CO_2 measurements by the carbon balance method. The following formula is dependent upon using Indolene 30 test fuel.

$$MPG = \frac{K_1}{K_2(HC, \frac{gm}{mi}) + K_3(CO, \frac{gm}{mi}) + K_3(CO_2, \frac{gm}{mi})}$$

where:

K_1 = 2423 = Carbon Content, gm/gallon of 1 gallon Indolene 30 Test Fuel

K_2 = 0.866 = Carbon Fraction of HC

K_3 = 0.429 = Carbon Fraction of CO

K_4 = 0.273 = Carbon Fraction of CO_2.

Each time a vehicle entered the program for emission testing, a vehicle engine parameter diagnosis form was filled out. This form provided data relative to emission measurements which account for changes in emission. In addition, maintenance records were kept for each repair or service that each vehicle received throughout the program.

Section 3

PROGRAM EVALUATION AND RESULTS

This section discusses the results of the analyses conducted for the program. It includes the study methodology, summary results, and a statistical treatment of the data.

3.1 STUDY METHODOLOGY

Test data were compiled from laboratory test forms to punched cards and, when testing was complete, transferred to magnetic tape. These data were used to compute minimum/maximum, mean, and standard deviations for HC, CO, NO_x, and fuel economy. The CVS and idle test data obtained during the test program was processed by computer to obtain means, standard deviation, and minimum and maximum levels for each parameter for the respective fleets, as a function of vehicle class (luxury, standard, intermediate, compact and subcompact), model-year (1968 to 1970, 1971, 1972, 1973, 1974), and test period. The data were evaluated and are presented in terms of quantifying the change in grams per mile as each category of vehicles accumulate mileage and time.

Specific statistical analyses for the categories and groups include:

- Evaluation of emission reduction from maintenance.

- Evaluation of degradation for groups and subgroups as a function time and mileage.

- Evaluation of emission reduction after final tune-up.

3.2 TEST PROGRAM RESULTS

Table 3-1 shows a summary of all test vehicles in each group. It provides a compilation of the mean gram-per-mile of each pollutant by group for each test interval. In addition, mean fuel economy in miles per gallon and mean odometer readings, and average cost of repair are presented.

As shown in the table, as-received HC emissions of Groups I and III and Groups II and IV are closely matched. However, the absolute value between the minimum and maximum emission data sets is 0.6 grams per mile. This represents a 15 percent difference between these groups.

This is to be expected with sample sizes this small. The CO and NO_x emission as-received values are more closely matched with about a 10 percent range between groups. As stated earlier, effectiveness of repair was a secondary objective while degradation with respect to various levels of maintenance was primary.

Fuel economy data, as calculated by the EPA carbon balance method, shows that the average of the four groups is approximately 14.5 miles per gallon in the as-received condition. A modest 2 percent improvement after maintenance was encountered. The fuel economy values are slightly higher than the national average 13.5 miles per gallon due to the larger mix of smaller vehicles within the groups as shown in Table 2-2.

Average odometer values are also listed for each group. As seen in Table 3-1, the Group IV vehicles started

Table 3-1. Test Program Data Summary

Parameter	As Received 0	After Maint. 0	1	3	6	9	12	After Final Maint. 12
			Test Interval (Months)					
Hydrocarbon (gpm)								
Group I	3.94	--	--	--	--	--	5.08	3.97
Group II	4.50	3.54	3.50	3.50	3.93	4.34	5.23	3.76
Group III	3.90	3.49	3.41	3.80	3.56	4.07	4.40	3.62
Group IV	4.50	3.58	3.63	3.68	4.52	3.97	5.65	4.03
Carbon Monoxide (gpm)								
Group I	56.6	--	--	--	--	--	62.7	52.0
Group II	58.4	49.8	51.0	50.7	56.1	57.9	52.2	51.2
Group III	59.7	48.1	47.8	48.4	51.1	54.6	54.3	46.4
Group IV	65.4	47.4	46.8	51.3	52.7	55.1	59.03	47.7
Oxides of Nitrogen (gpm)								
Group I	3.92	--	--	--	--	--	3.60	3.56
Group II	4.24	4.36	4.77	4.11	4.08	4.08	3.99	4.01
Group III	3.77	3.91	4.02	3.95	4.01	4.20	3.98	3.93
Group IV	3.71	3.94	3.98	4.12	3.71	3.31	3.01	3.21
Fuel Economy (mpg)								
Group I	14.31	--	--	--	--	--	13.17	13.24
Group II	14.96	15.15	15.06	14.86	15.02	14.63	14.42	14.87
Group III	14.36	14.68	14.71	14.77	14.94	14.43	14.04	14.16
Group IV	14.45	14.77	14.61	13.97	13.90	13.77	13.56	13.88
Average Odometer (mile)								
Group I	34,927	--	--	--	--	--	48,501	48,501
Group II	32,679	32,701	33,841	35,445	38,824	42,832	44,375	44,375
Group III	35,013	35,033	35,903	38,034	41,564	45,748	46,905	46,905
Group IV	39,835	38,859	40,516	42,435	45,942	46,868	48,151	48,151
Number of Vehicles								
Group I	144	--	--	--	--	--	91	91
Group II	144	144	137	126	118	110	109	109
Group III	144	144	142	132	121	115	112	112
Group IV	144	144	141	133	126	116	114	114
Average Repair Cost ($)								
Group I	--	0	--	--	--	--	32.36	52.31
Group II	--	14.15	1.84	3.90	7.91	11.84	10.77	33.90
Group III	--	51.76	3.01	8.39	16.37	22.91	14.10	43.93
Group IV	--	57.93	3.76	5.74	9.86	9.91	8.25	60.34

with a higher value than the other groups. This is due to the fact that Group IV was added to the experiment nearly 7 months after the start of this program.

Table 3-1 also shows the attrition encountered for each group during the 1-year test program. The main causes of attrition were transfer of ownership, moved out of area, collision damage, and loss of interest in the program. Attrition by group ranged from a low of 20 percent for Group IV to a high of 39 percent for Group I.

As a matter of interest, Group II was analyzed with respect to both failed and passed sub-groups. Table 3-2 shows a similar breakdown of the pertinent data.

Table 3-3 lists the percentage change of emission of each group as a function of time. Test 2, the baseline after maintenance, was used as the normalized reference point with respect to all other test points. In the case of Group I where no maintenance was performed, the average of Groups II, III, and IV were used to generate an estimated value. Therefore, the true degradation for Group I occurs from the baseline test to the final test at 12 months.

The degradation by pollutant is graphically presented in Figures 3-1 through 3-3. Histograms were generated to show graphically how the emissions changed during the 12-month period. Hydrocarbon emissions degraded the most at the end of the 12-month period. Group II degraded over 45 percent, while Group IV experienced the smallest amount of degradation in HC emissions of 26 percent. It should be pointed out that Group III was the controlled maintenance group. All manufacturer's maintenance schedules were followed during the 12-month period. This maintenance included oil and filter changes and all other emission-required maintenance, as specified by the manufacturer. All maintenance after Test 2 of all other groups was owner-initiated only. These were mainly originated from emission component failure or maladjustments.

Table 3-2. TEST PROGRAM DATA SUMMARY (Group II)

Parameter	As Received 0	After Maint. 0	1	3	6	9	12	After Final Maint. 12
				Test Interval (Months)				
Hydrocarbon (gpm)								
Group II Pass	3.33	3.33	3.35	3.25	3.70	4.13	3.87	3.40
Group II Fail	6.2	3.86	3.69	3.82	4.19	4.60	6.90	4.20
Group II (All)	4.5	3.54	3.50	3.50	3.93	4.37	5.23	3.76
Carbon Monoxide (gpm)								
Group II Pass	49.0	49.0	53.2	49.4	56.1	58.5	59.2	52.0
Group II Fail	71.8	50.9	48.1	52.5	56.0	57.3	70.4	50.2
Group II (All)	58.4	49.8	51.0	50.7	56.1	57.9	52.2	51.2
Oxides of Nitrogen (gpm)								
Group II Pass	4.33	4.33	5.0	4.10	3.97	4.1	4.01	3.96
Group II Fail	4.11	4.41	4.47	4.14	4.2	4.06	3.95	4.07
Group II (All)	4.24	4.36	4.77	4.11	4.08	4.08	3.99	4.01
Fuel Economy (mpg)								
Group II Pass	14.70	14.70	14.31	14.45	14.83	14.46	14.36	14.80
Group II Fail	15.32	15.79	16.07	15.38	15.24	14.84	14.48	14.97
Group II (All)	14.96	15.15	15.06	14.86	15.02	14.63	14.42	14.87
Average Odometer (mile)								
Group II Pass	29,295	29,295	30,344	30,925	33,758	37,666	40,081	40,081
Group II Fail	37,609	37,609	38,606	41,094	44,827	49,032	49,634	49,634
Group II (All)	32,679	32,701	33,841	35,445	38,824	42,832	44,375	44,375
Number of Vehicles								
Group II Pass	85	85	79	70	64	60	60	60
Group II Fail	59	59	58	56	54	50	49	49
Group II (All)	144	144	137	126	118	110	109	109
Average Repair Cost ($)								
Group II Pass	-	0	0.10	3.53	11.97	9.71	10.94	35.17
Group II Fail	-	26.24	3.99	4.35	2.90	14.46	10.56	32.34
Group II (All)	-	14.15	1.84	3.90	7.91	11.84	10.77	33.90

Table 3-3. PERCENT CHANGE OF EMISSION AS A FUNCTION OF TIME

Test Interval (Months)

Pollutant	As Received 0	After Maint. 0*	1	3	6	9	12	After Final Maint. 12
Hydrocarbons								
Group I	--	0	--	--	--	--	28.9	1.0
Group II	27.1	0	-1.1	-1.1	11.0	11.0	47.7	6.2
Group III	11.7	0	-1.2	8.9	2.0	16.6	26.0	3.8
Group IV	25.7	0	1.4	2.8	26.2	10.9	57.8	12.6
Carbon Monoxide								
Group I	--	0	--	--	--	--	10.8	-8.2
Group II	17.3	0	2.4	1.8	12.6	16.3	24.9	2.8
Group III	24.1	0	-0.6	0.6	6.2	13.5	12.9	-3.5
Group IV	38.0	0	-1.3	8.2	11.2	16.2	25.1	0.6
Oxides of Nitrogen								
Group I	--	0	--	--	--	--	-8.2	-9.2
Group II	-2.8	0	9.4	-5.7	-5.4	-6.4	-8.5	-8.1
Group III	-3.6	0	2.8	1.0		7.4	1.8	0.5
Group IV	-5.8	0	1.0	4.6	-5.8	-16	-23.6	-18.5

*Normalized Reference

Figure 3-1. HC EMISSION DEGRADATION VS. TIME

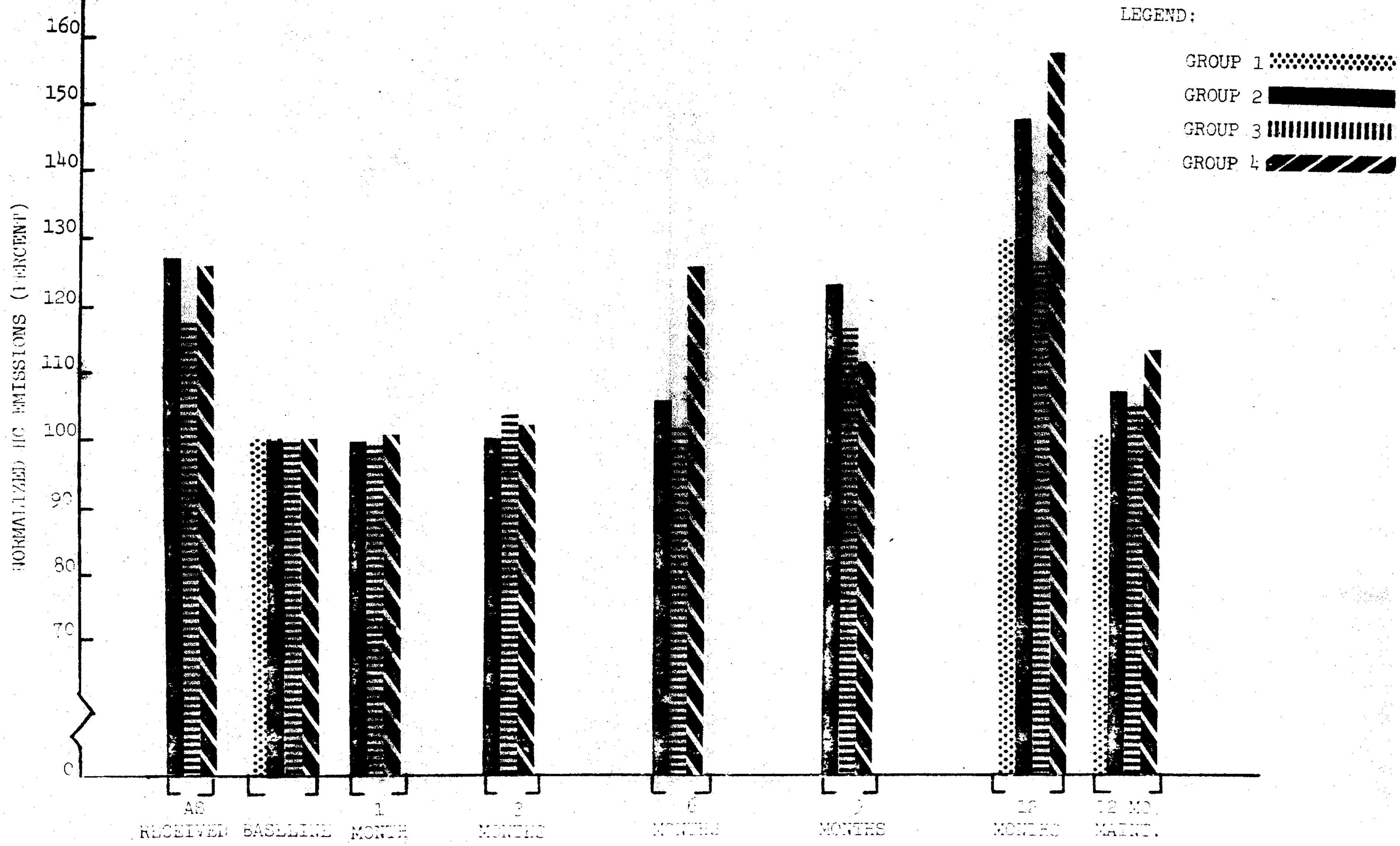


Figure 3-2. CO EMISSION DEGRADATION VS. TIME

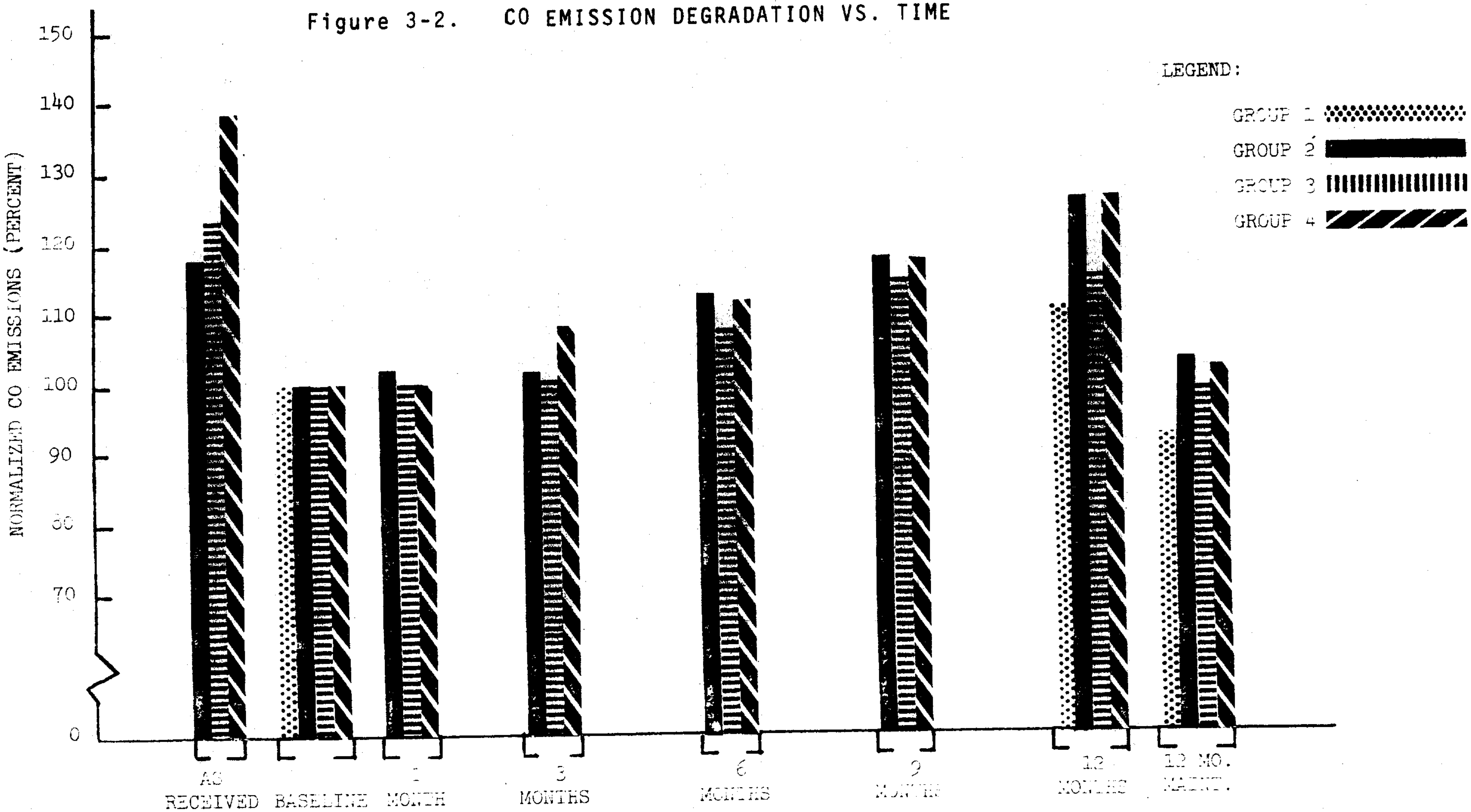
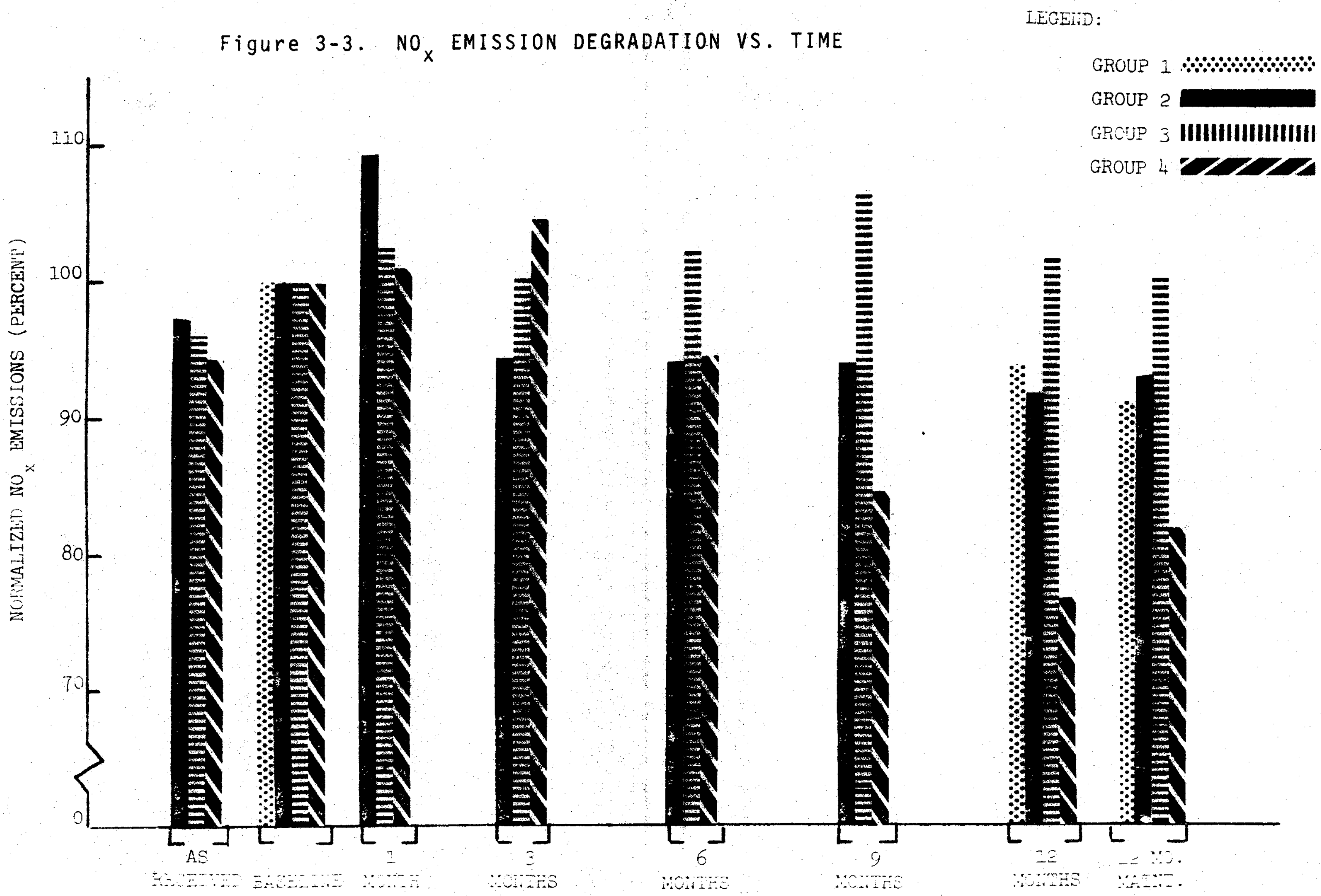


Figure 3-3. NO_x EMISSION DEGRADATION VS. TIME



Carbon monoxide emissions degraded for a high of 25 percent for Groups II and IV to a low of 13 percent for Group III over the 12-month period. CO emissions by group over the 12 months tended to degrade more uniformly than the HC emissions.

Finally, NO_x emissions, as expected, decreased inversely to the increase in CO emission. Group IV decreased 23 percent at the end of the 12 months; while Group II, decreased 8.5 percent. Group III was nearly the same at the end of the 12 months as at the beginning.

3.2.1 Idle Emission Summary

All vehicles throughout the program were subjected to a low and high rpm idle test. Table 3-4 lists the mean HC (ppm) and CO (%) values for each group by rest period. As can be seen in the table, reductions in idle emission were obtained after both tune-ups. However, the degradation in emission thoghout the year was not as pronounced as that obtained using the FTP exhaust emission test procedures.

3.3 STATISTICAL ANALYSES

In order to determine the best fit line(s) which defines the shape of the degradation curve, a stepwise regression was performed on the data. The data was generated from the master tape to produce a tape which included all test data of interest. The data contained all emission data along with calculated fuel consumption for each group. In addition, the independent variables included time-in days and miles driven since original maintenance (Test 2).

The Biomedical Computer Program computed a sequence of multiple linear regression equations in stepwise manner. At each step one variable was added to the regression equation. Output from the program includes:

Table 3-4. IDLE TEST PROGRAM DATA SUMMARY

	Test Interval (Months)							
Parameter	As Received 0	After Maint. 0	1	3	6	9	12	After Final Maint. 12
Idle Hydrocarbon (ppm)								
Group I	249	--	--	--	--	--	158	119
Group II	263	146	160	153	176	152	188	127
Group III	208	154	151	181	133	148	139	106
Group IV	216	161	163	131	156	113	128	119
2500 rpm Hydrocarbon (ppm)								
Group I	120	--	--	--	--	--	106	73
Group II	150	93	97	106	115	183	126	85
Group III	103	84	102	96	74	114	99	73
Group IV	99	86	91	93	104	78	119	95
Idle Carbon Monoxide (%)								
Group I	2.92	--	--	--	--	--	1.96	1.09
Group II	2.62	1.32	1.64	1.81	1.82	1.76	1.83	1.13
Group III	2.73	1.24	1.50	1.69	1.77	1.58	1.51	1.08
Group IV	2.78	1.16	1.29	1.24	1.27	1.22	1.43	0.83
2500 rpm Carbon Monoxide (%)								
Group I	0.85	--	--	--	--	--	0.58	0.56
Group II	0.77	0.59	0.61	0.63	0.71	0.61	0.68	0.57
Group III	0.88	0.52	0.54	0.53	0.62	0.49	0.49	0.42
Group IV	0.86	0.69	0.60	0.60	0.78	0.55	0.74	0.53

a) Multiple R

b) Standard error of estimate

c) Analysis-of-variance table

d) Regression coefficients

The variables were forced into the regression equation to obtain linear, quadratic, and cubic polynomials.

A series of 40 regressions were obtained in order to plot scattergrams of individual points and the corresponding linear, quadratic, and cubic regression lines. Figures 3-4 through 3-43 are the degradation curves for Groups II, II passed, II failed, III, and IV for HC, CO, NO_x, and fuel consumption as a function of time-in days and miles. In addition, each point on all plots was coded with respect to weight class. The following coding applies to all scattergrams.

□ Luxury

△ Standard

+ Intermediate

× Compact

◇ Subcompact

Finally, Appendix A includes 126 plots of Group II, III, and IV for HC, CO, and NO_x for each model-year (1968 through 1974) as a function of time-in days and miles. Computer printout of each regression is being transmitted separately because of the volume of the data.

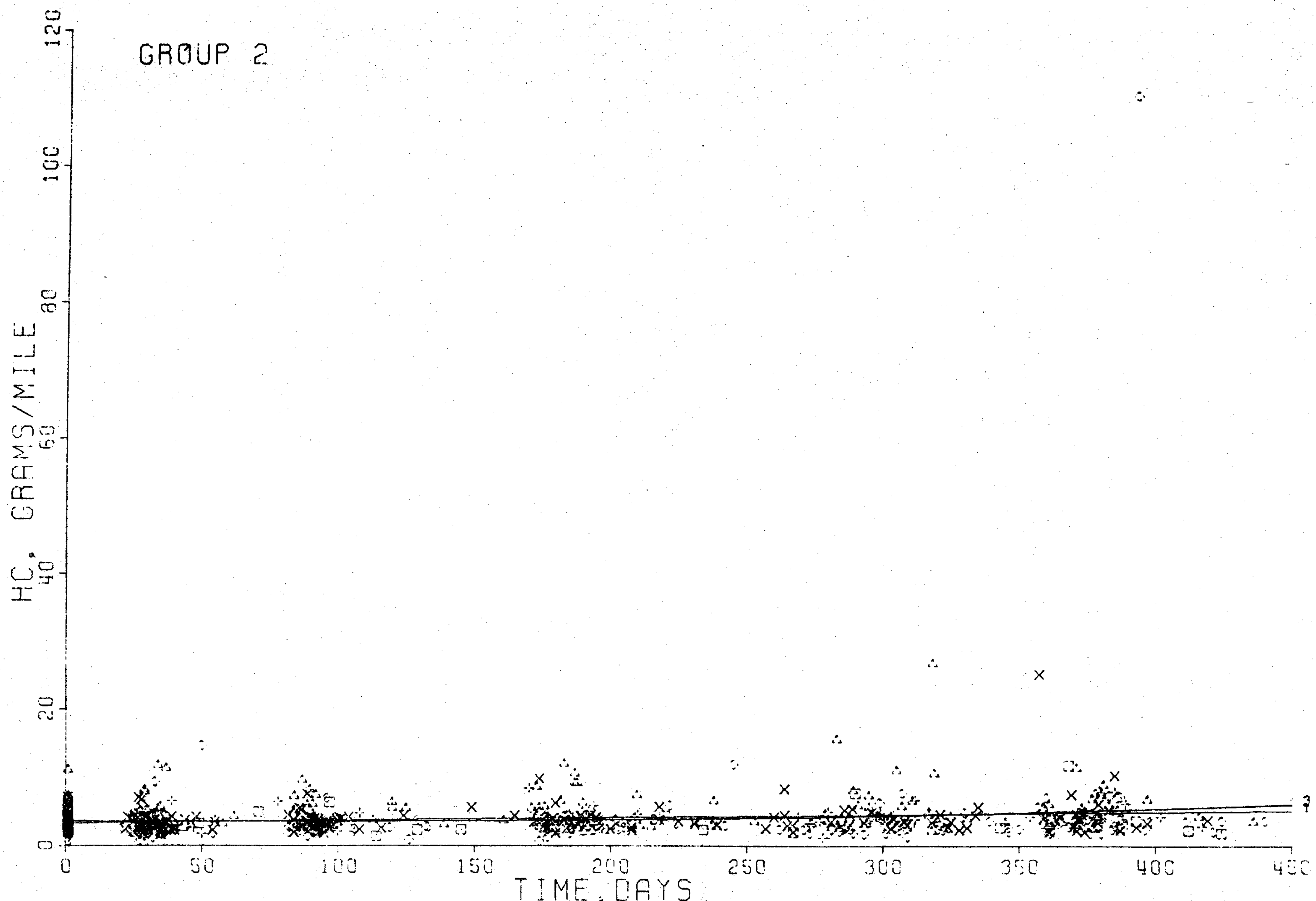


Figure 3-4. DEGRADATION VS. TIME

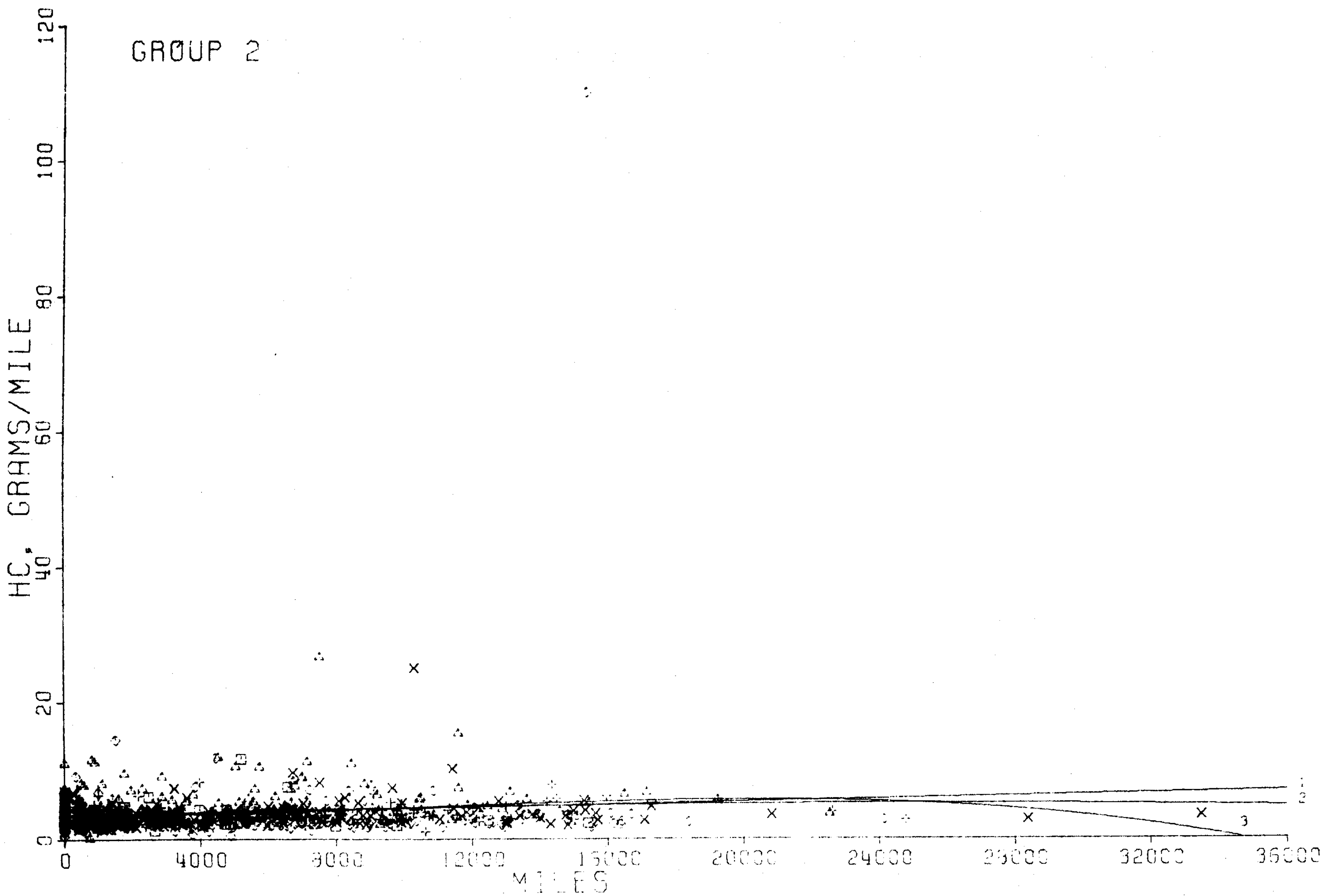


Figure 3-5. DEGRADATION VS. MILES

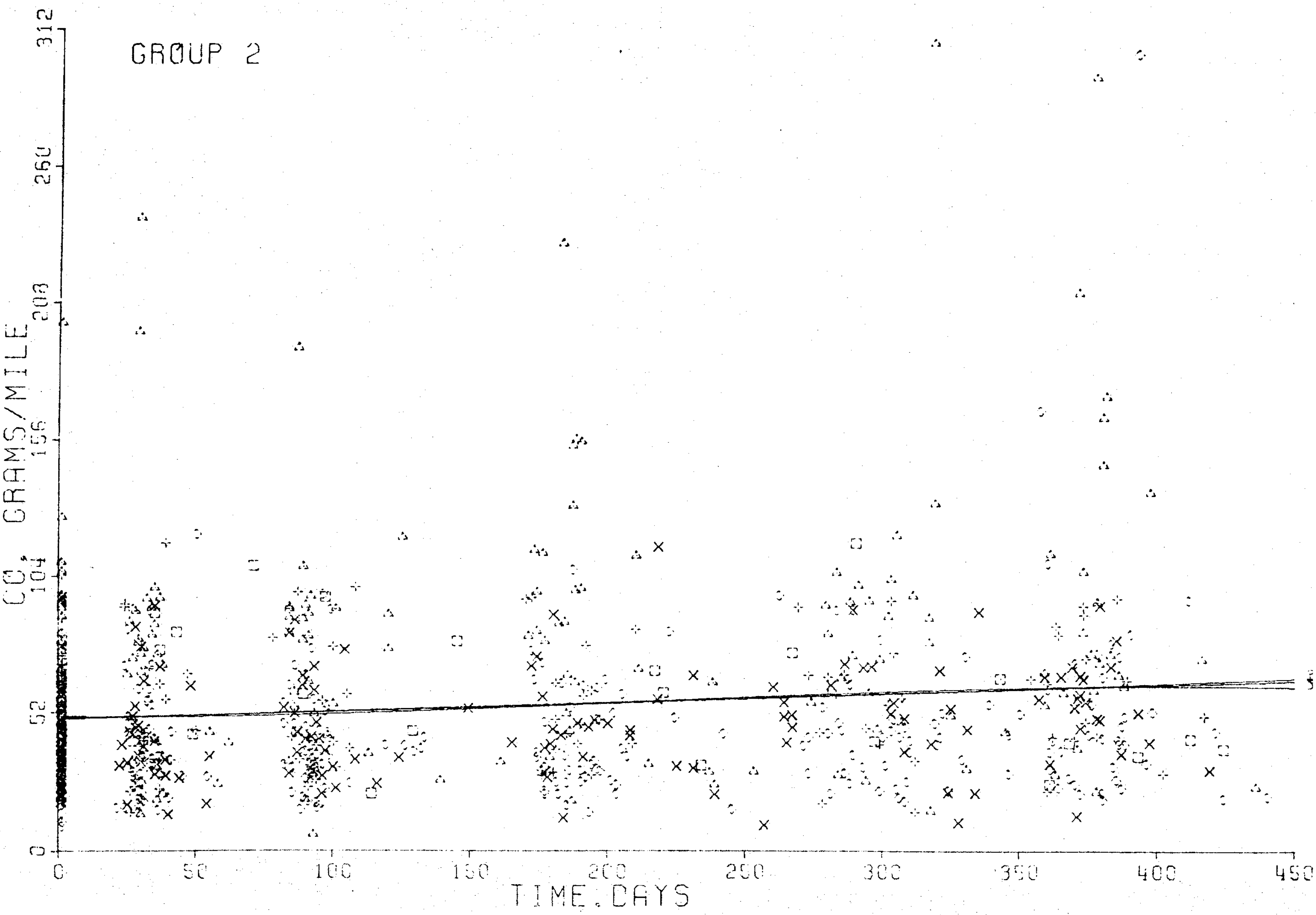


Figure 3-6. DEGRADATION VS. TIME

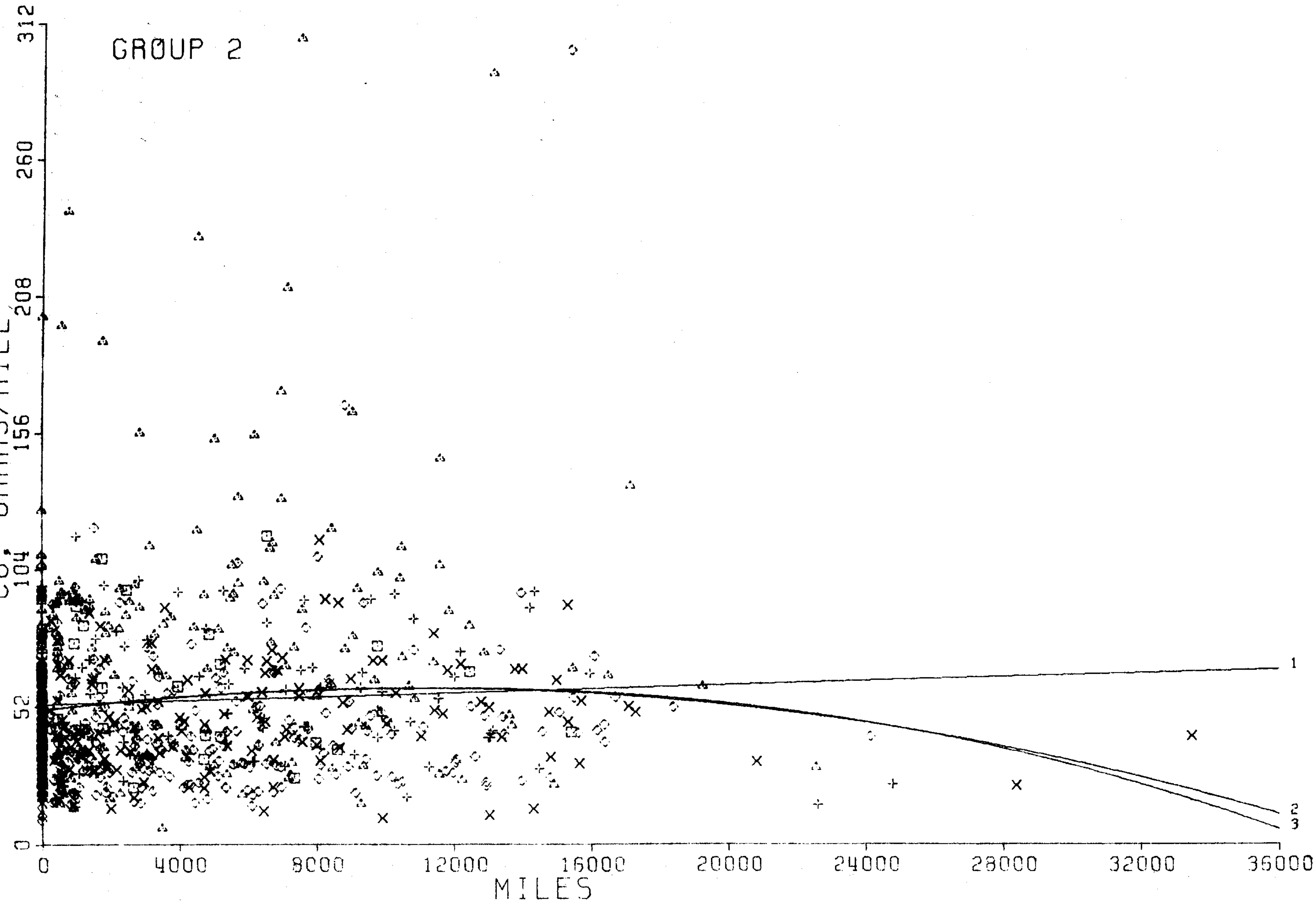


Figure 3-7. DEGRADATION VS. MILES

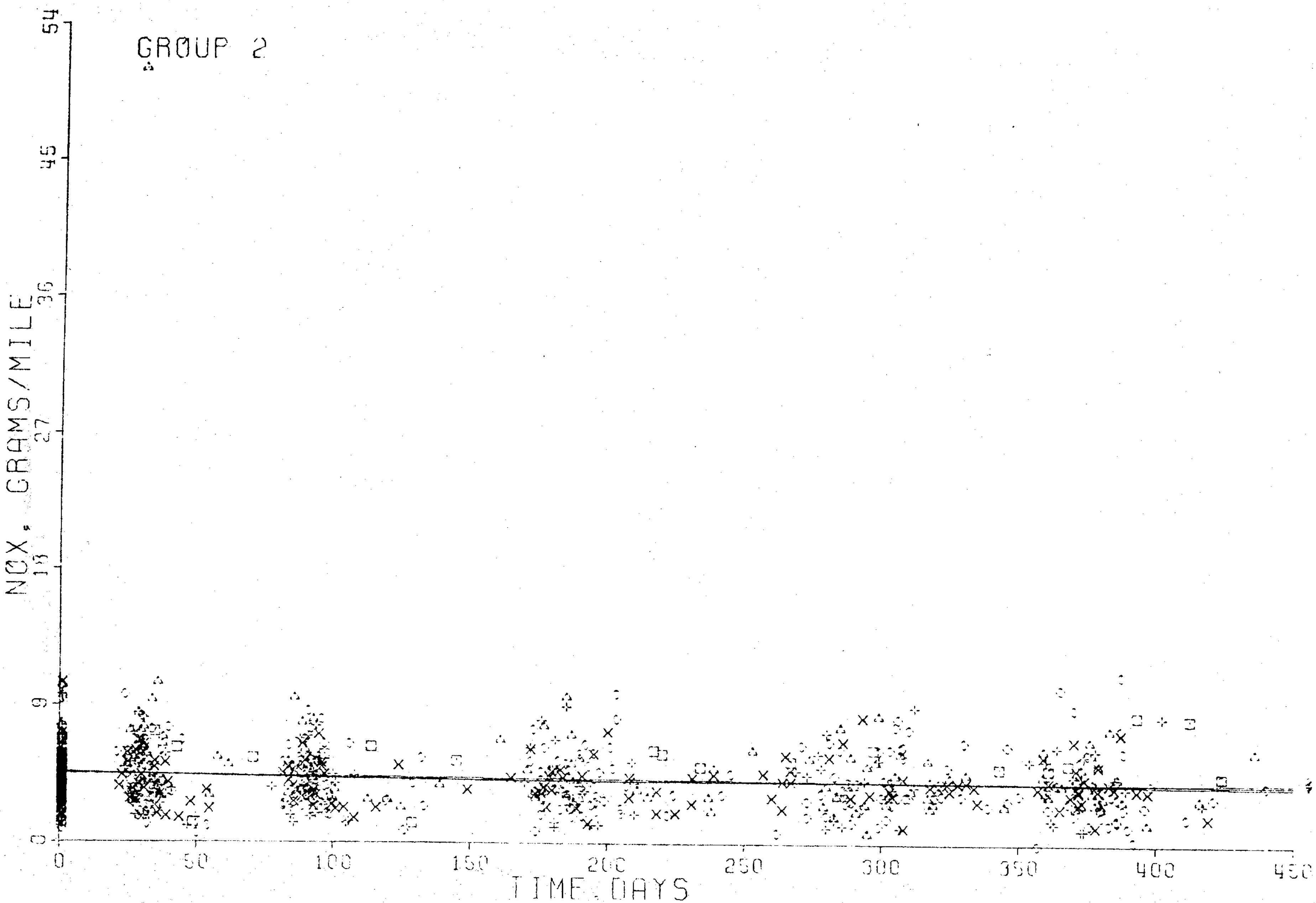


Figure 3-8. DEGRADATION VS. TIME

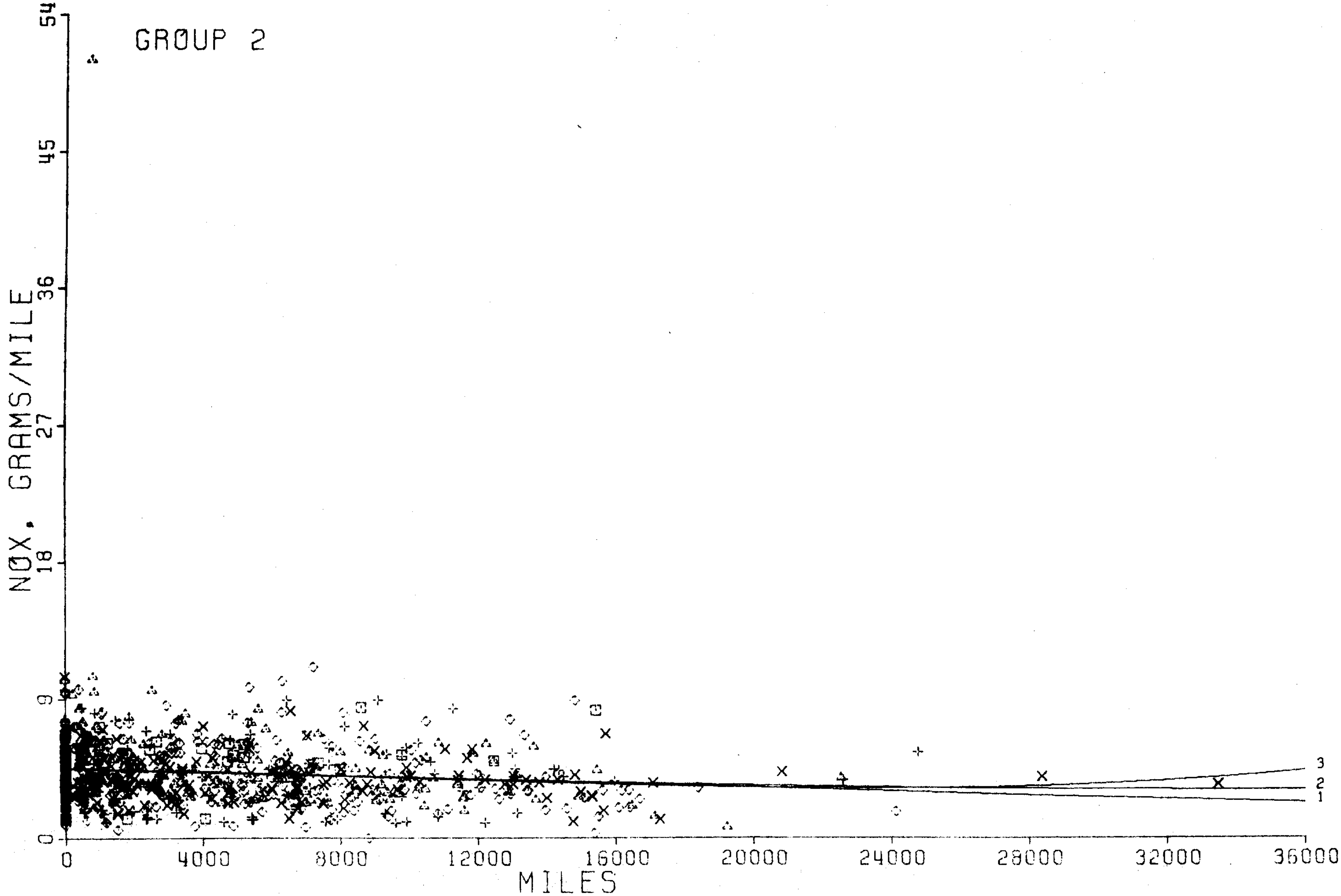


Figure 3-9. DEGRADATION VS. MILES

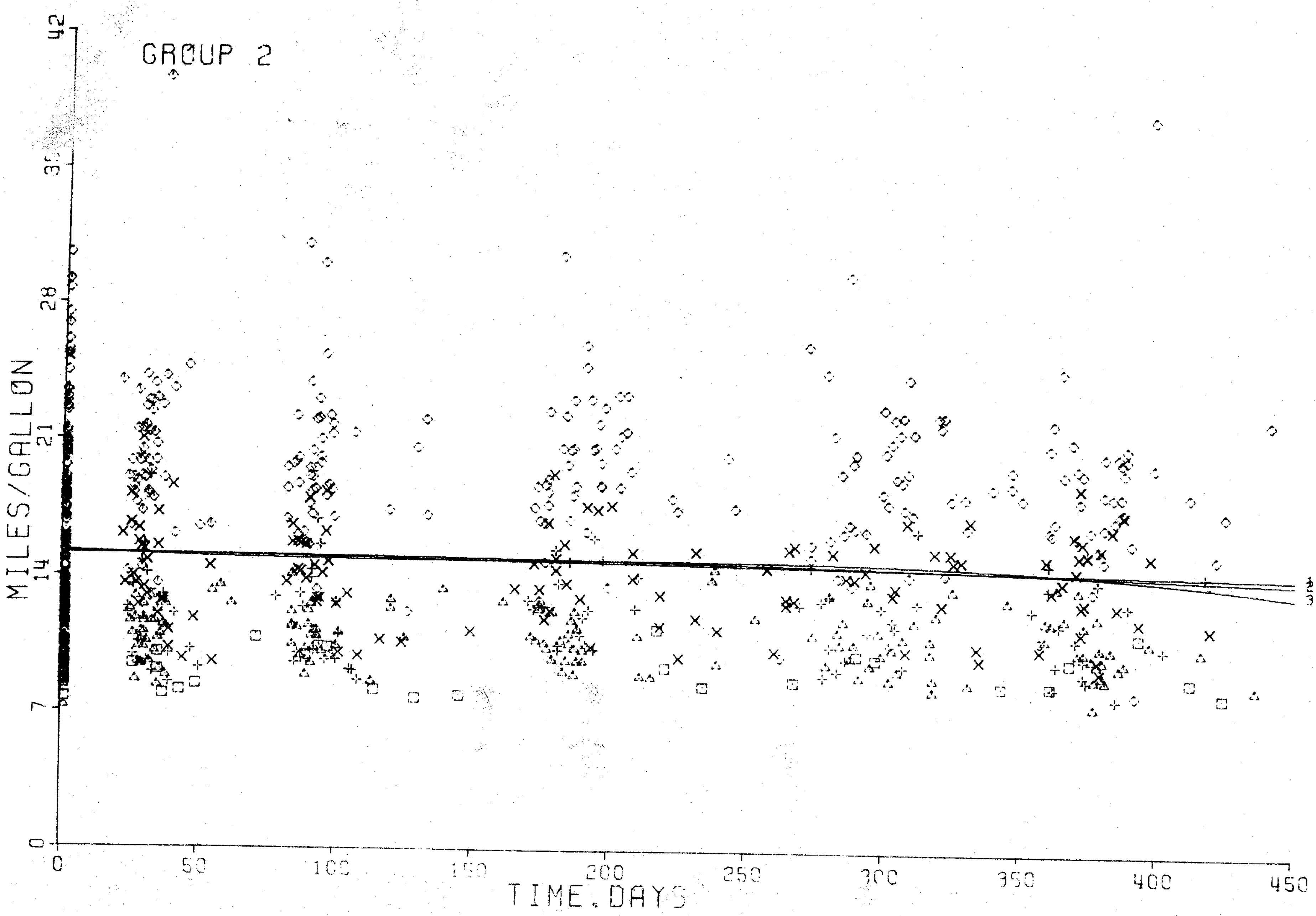


Figure 3-10. DEGRADATION VS. TIME

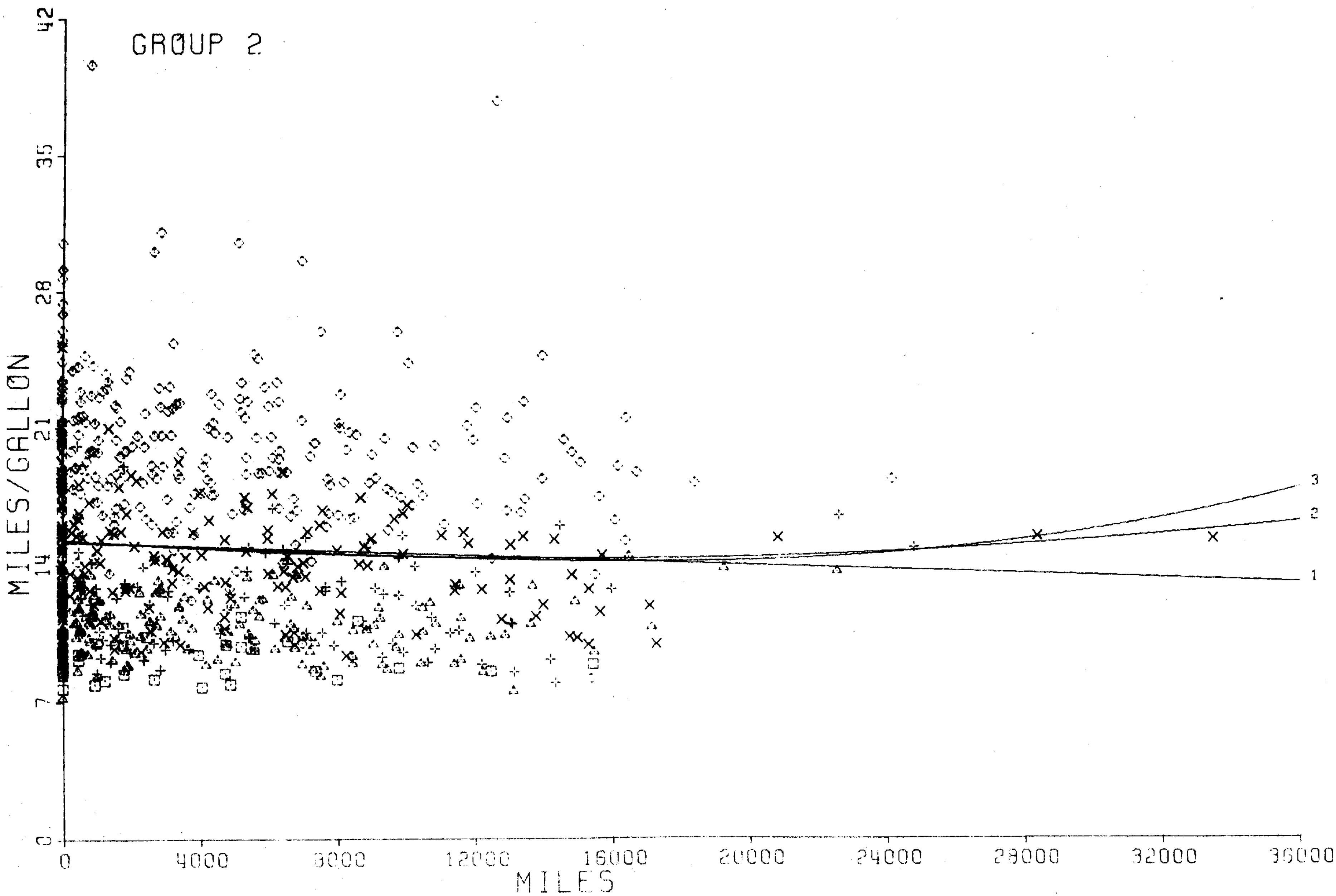


Figure 3-11. DEGRADATION VS. MILES

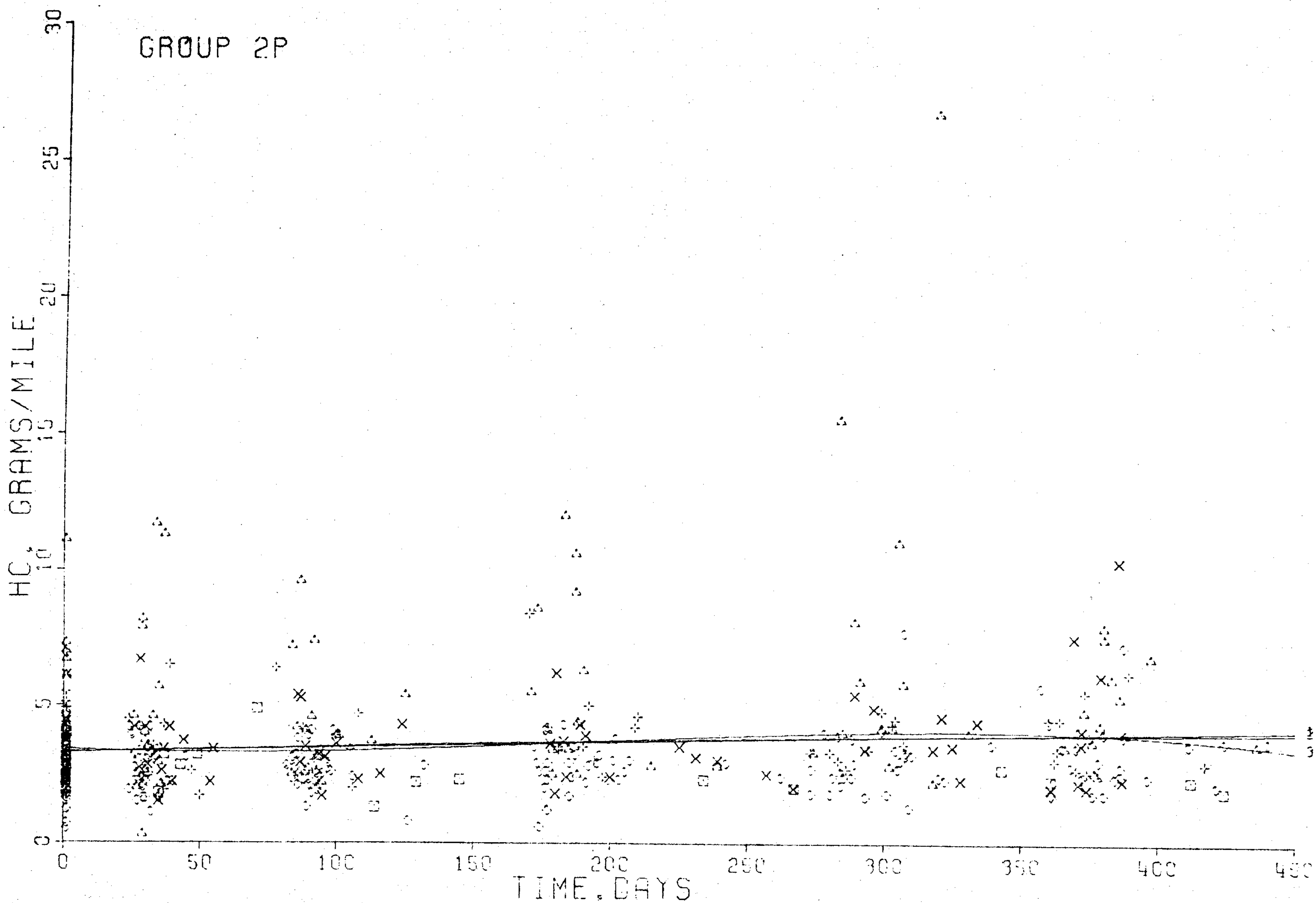


Figure 3-12. DEGRADATION VS. TIME

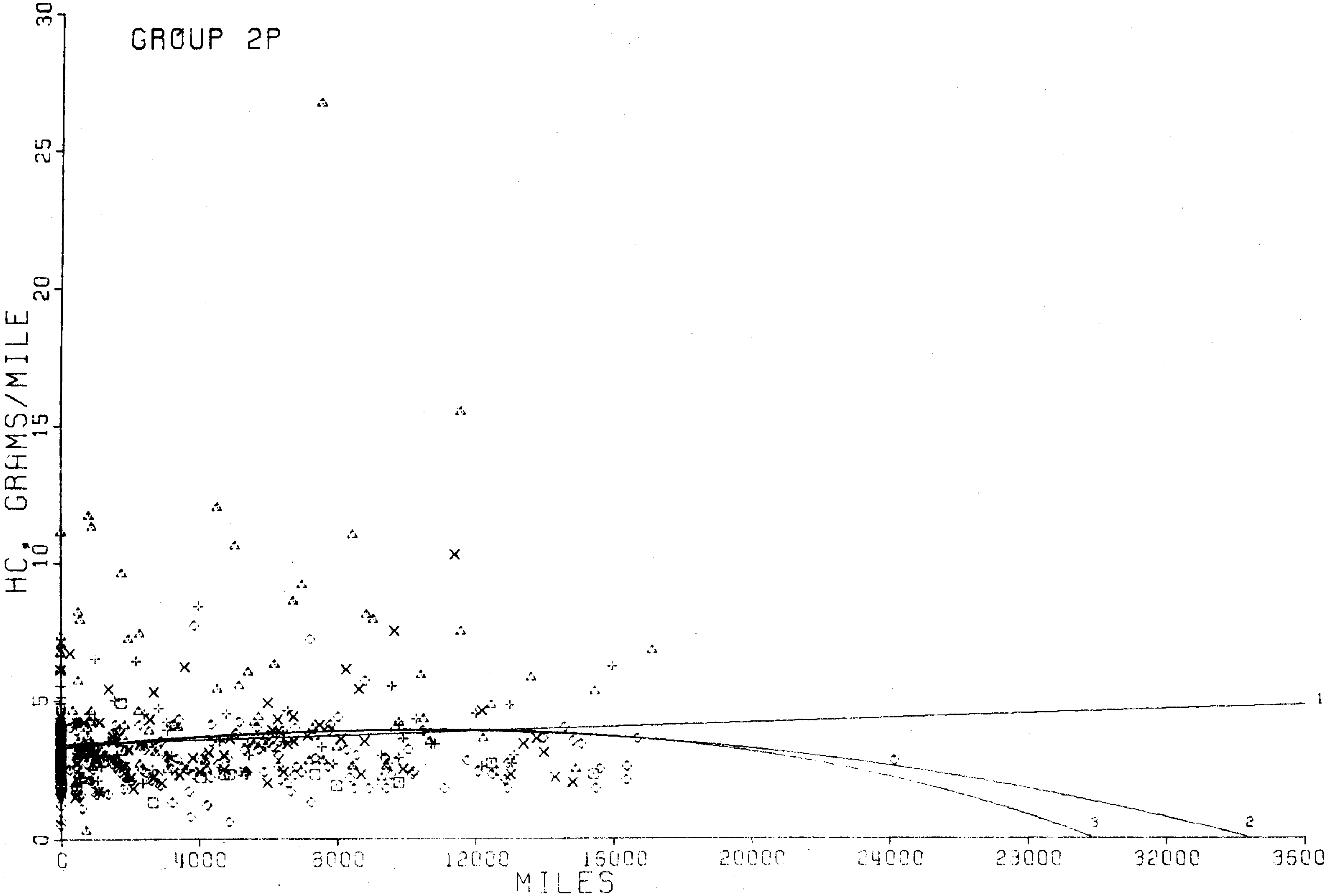


Figure 3-13. DEGRADATION VS. MILES

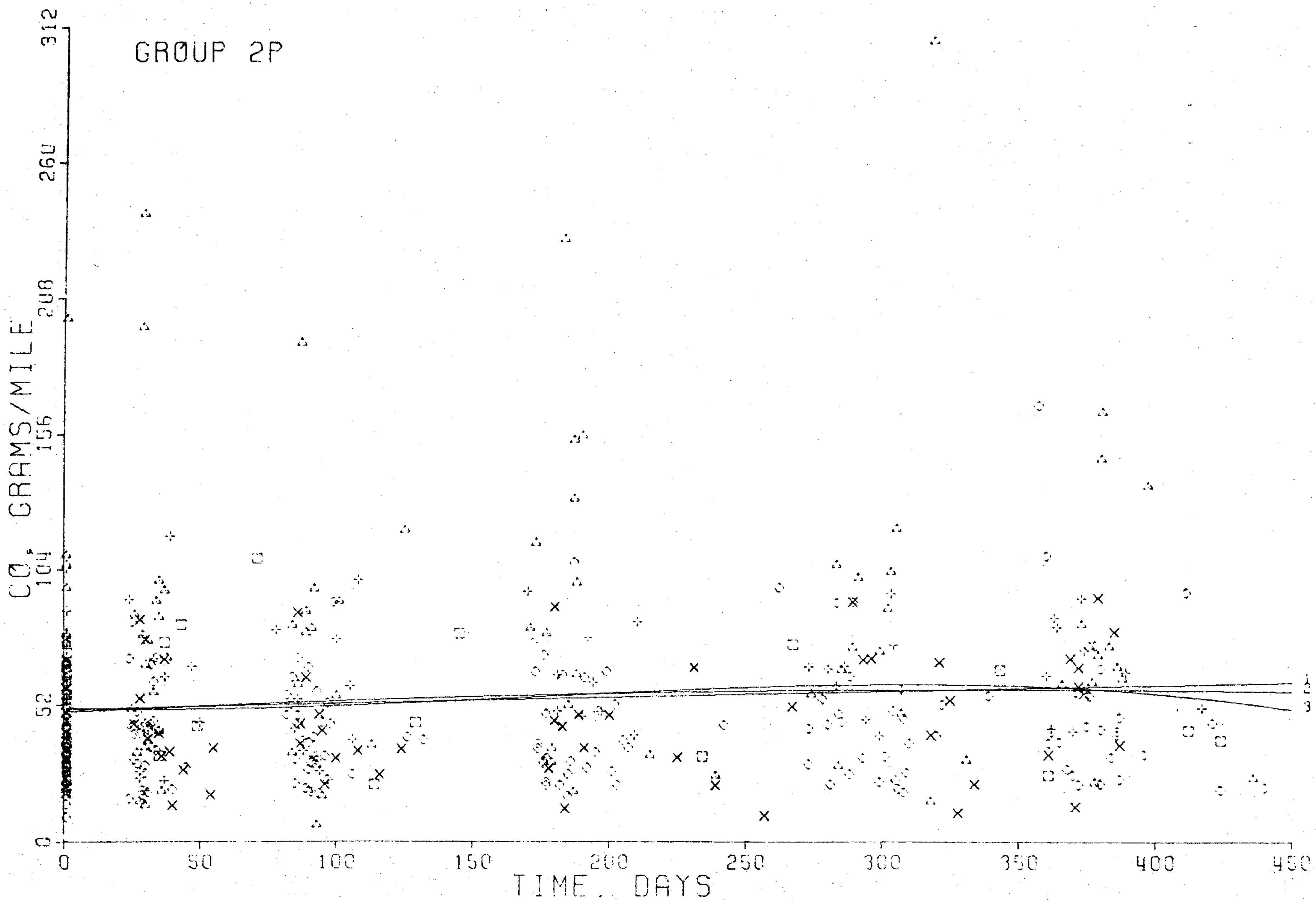


Figure 3-14. DEGRADATION VS. TIME

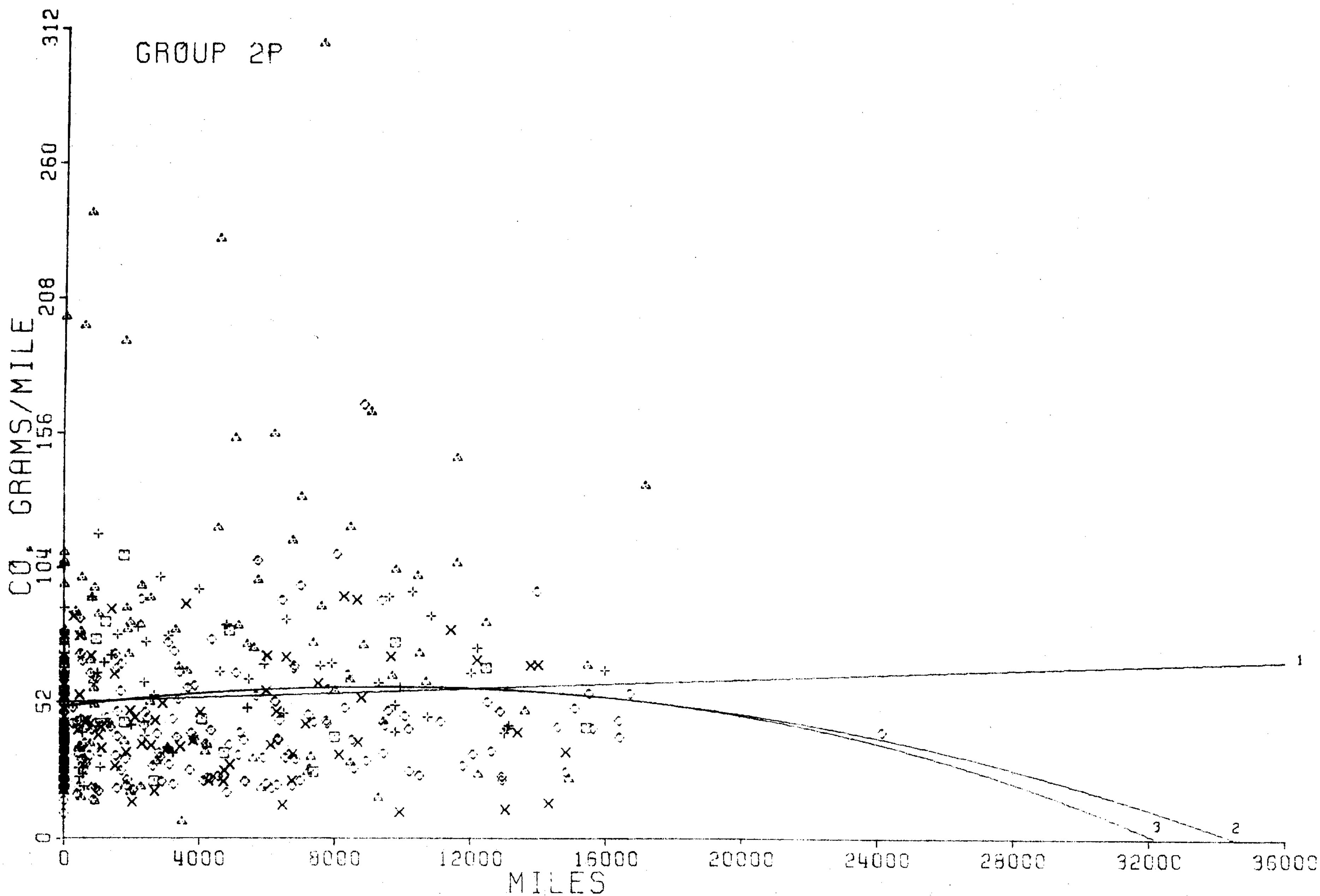


Figure 3-15. DEGRADATION VS. MILES

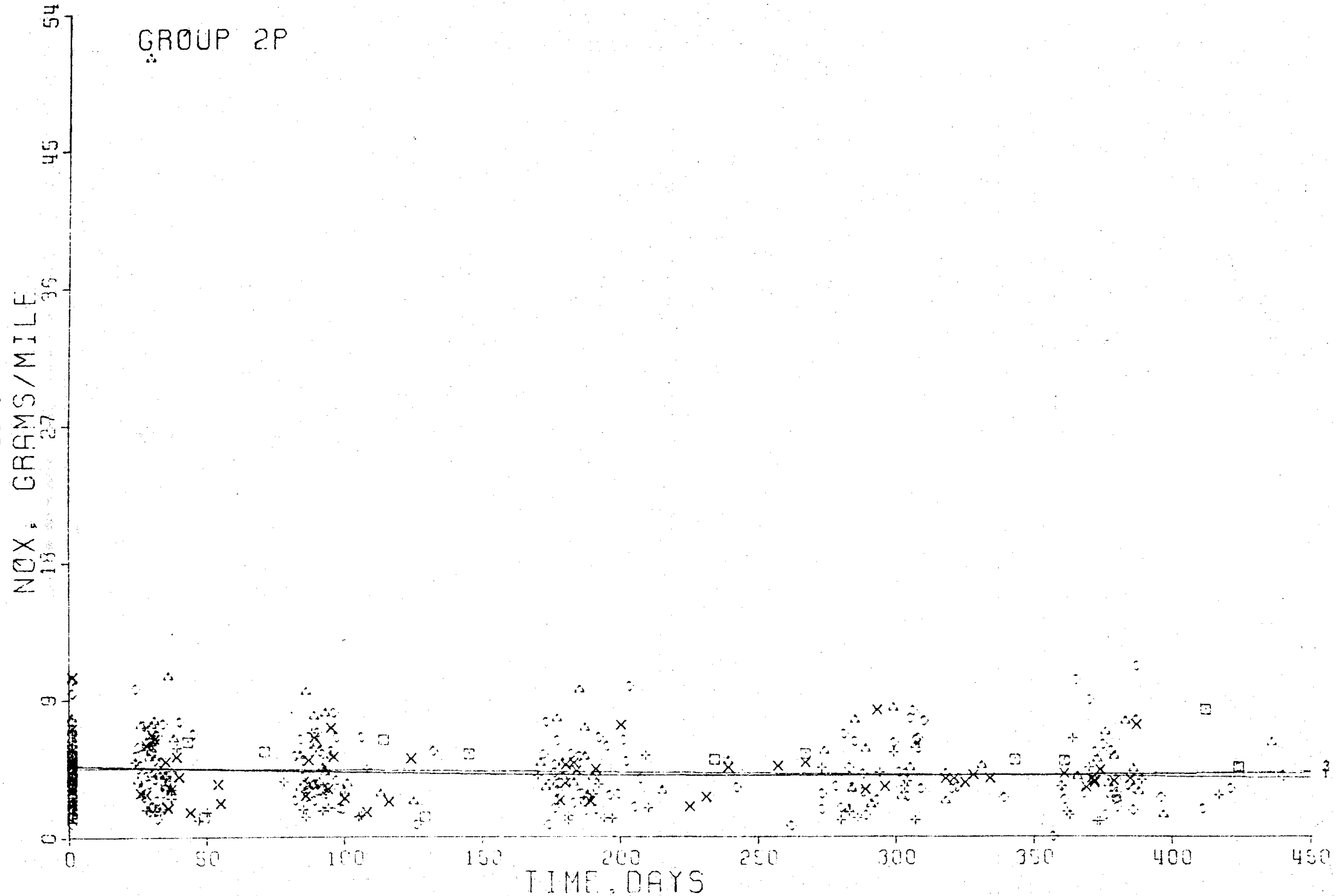


Figure 3-16. DEGRADATION VS. TIME

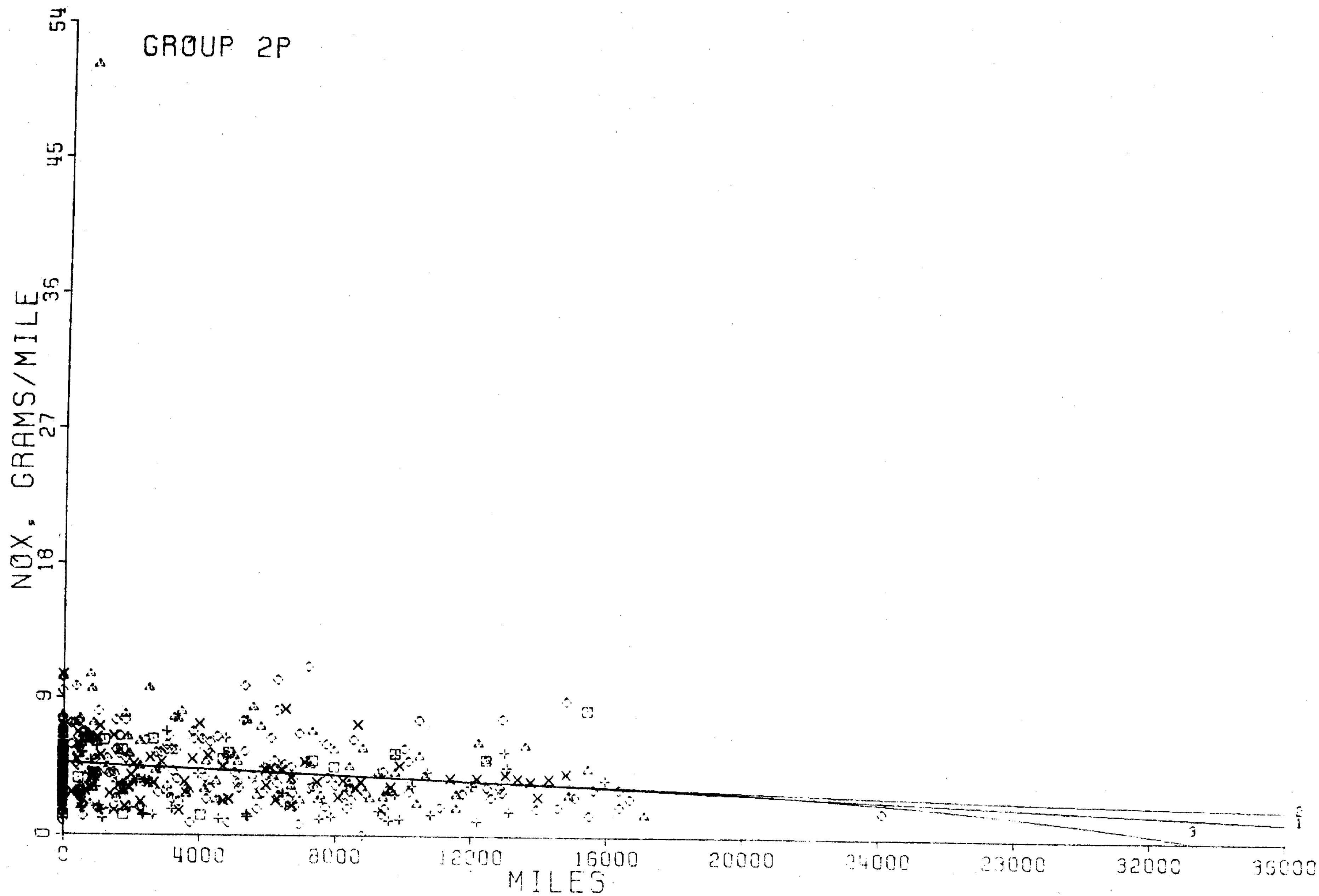


Figure 3-17. DEGRADATION VS. MILES

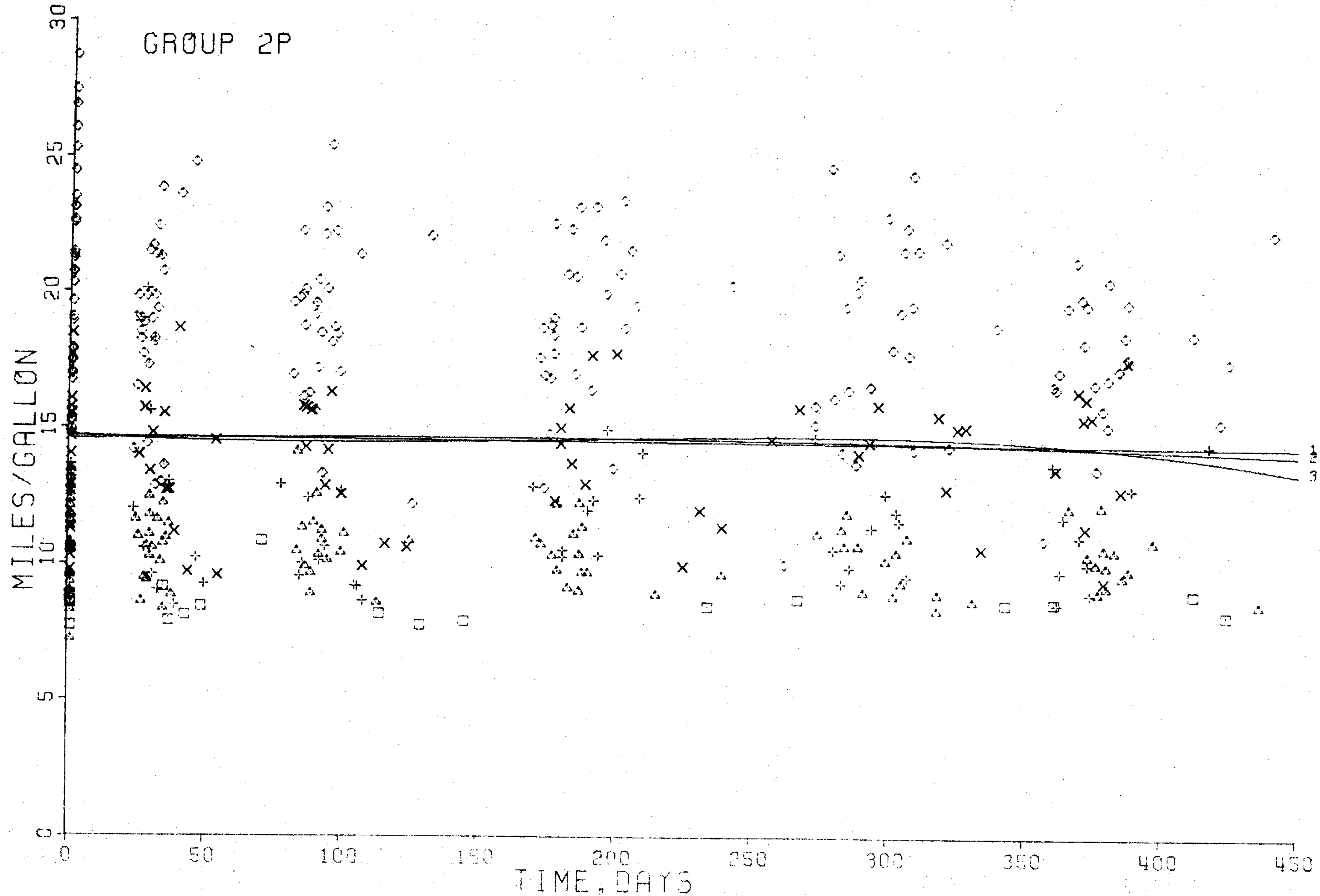


Figure 3-18. DEGRADATION VS. TIME

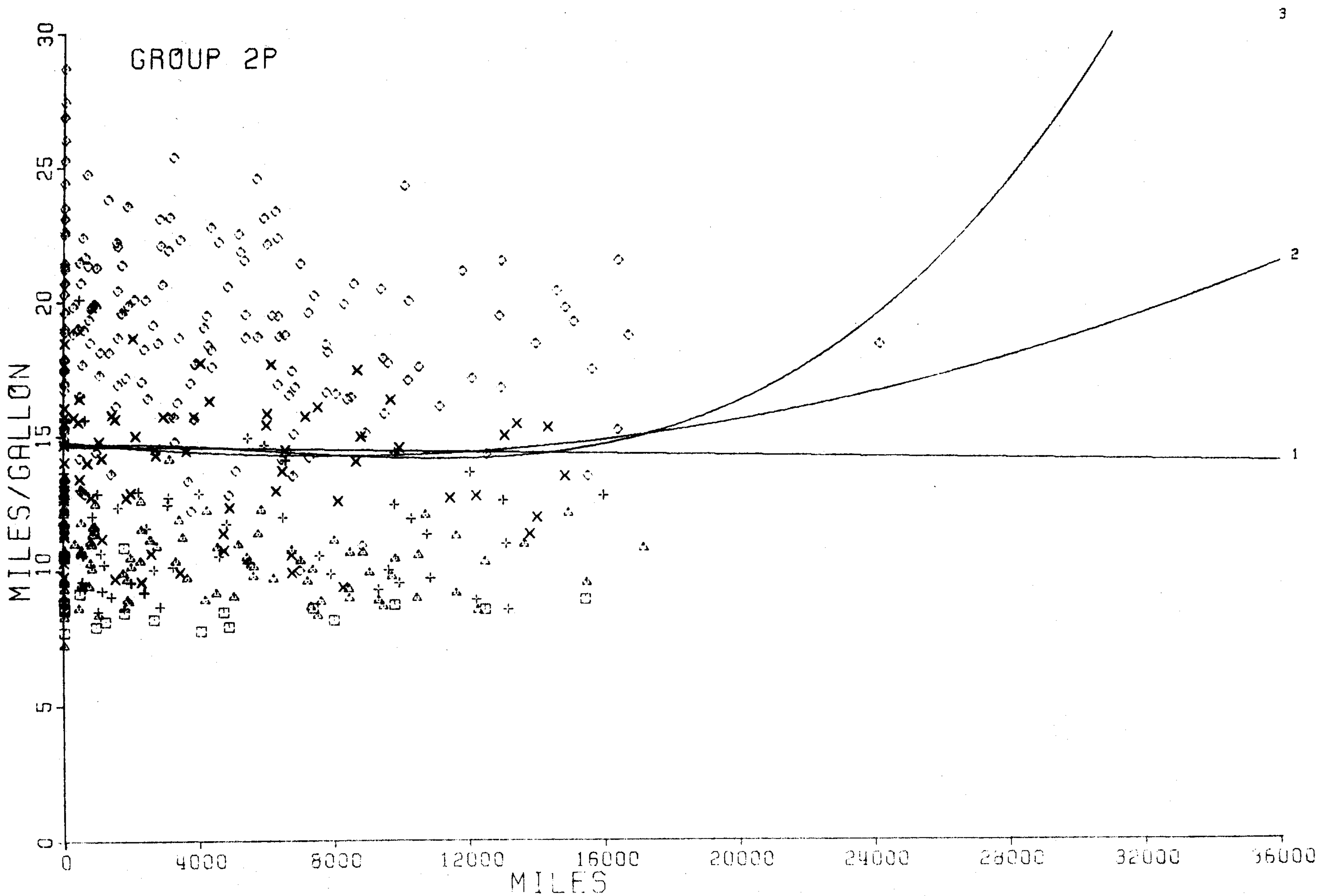


Figure 3-19. DEGRADATION VS. MILES

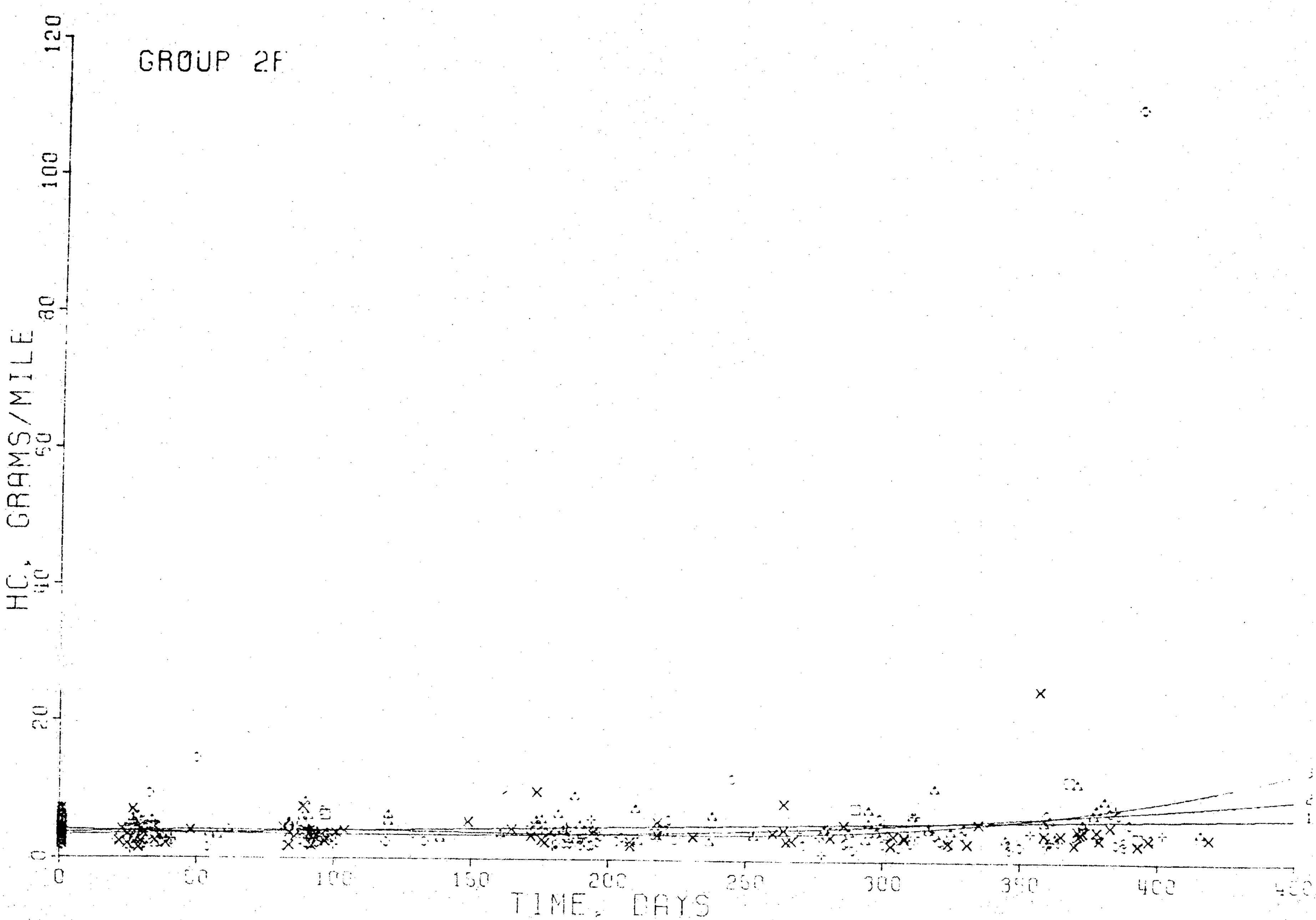


Figure 3-20. DEGRADATION VS. TIME

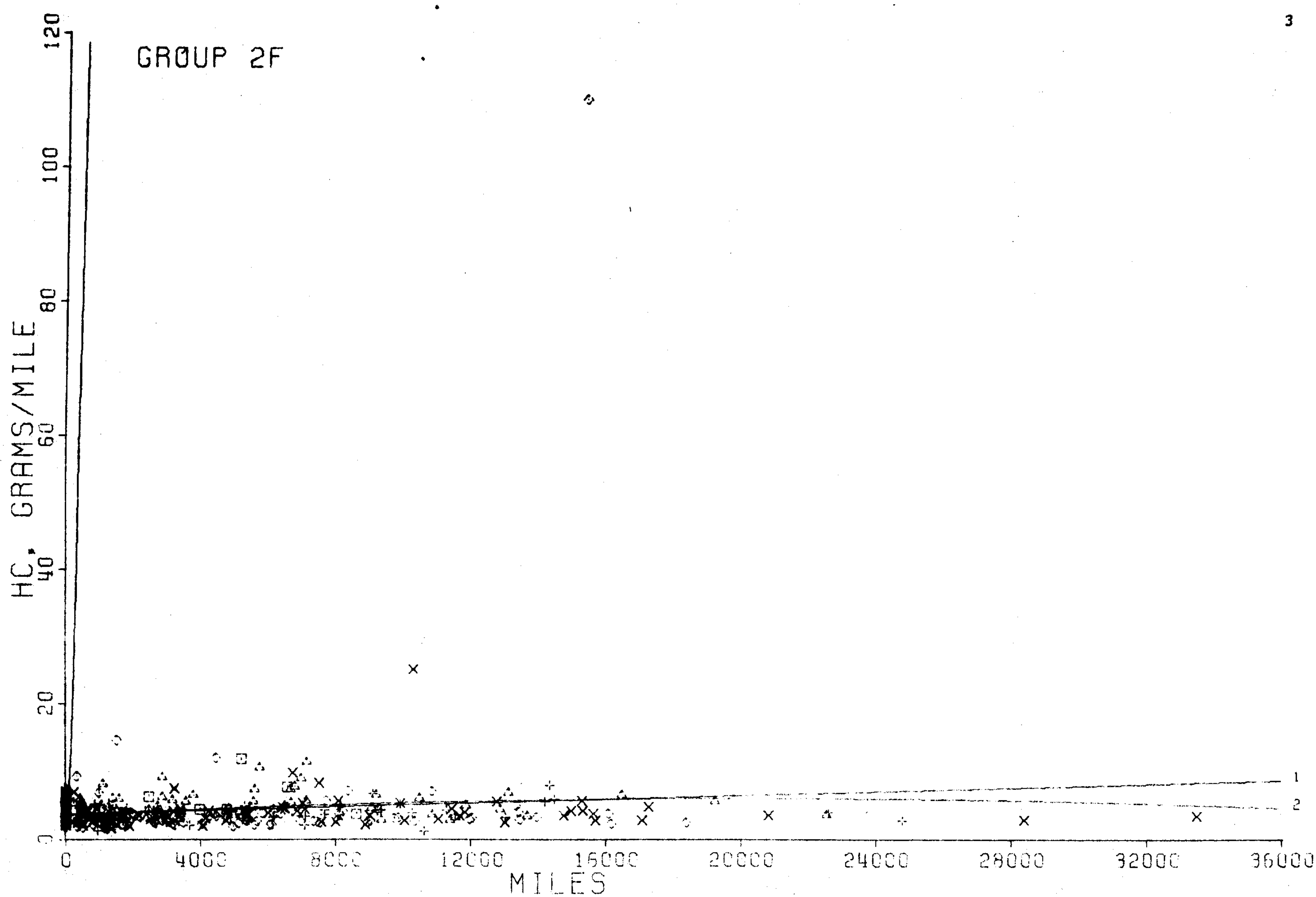


Figure 3-21. DEGRADATION VS. MILES

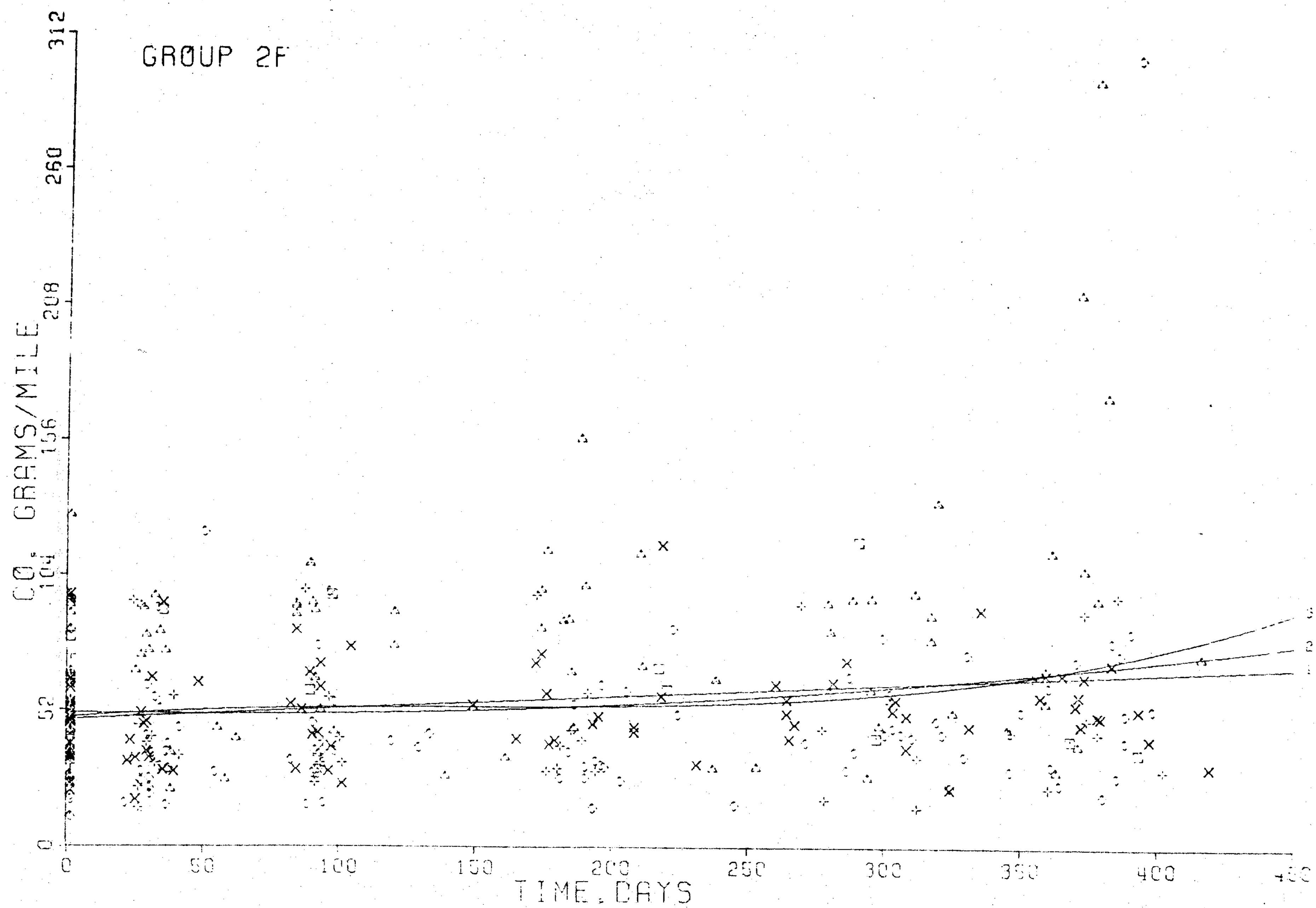


Figure 3-22. DEGRADATION VS. TIME

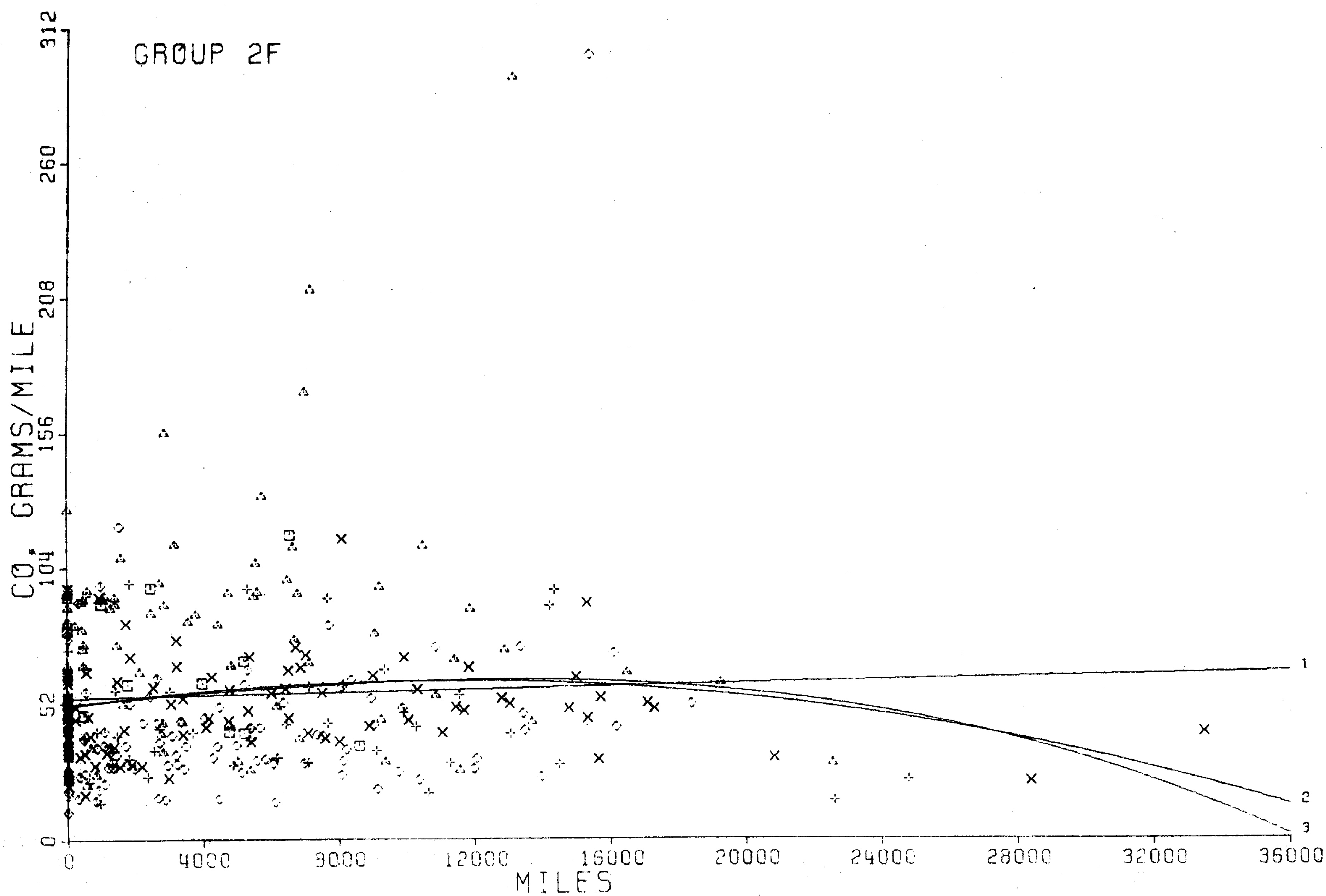


Figure 3-23. DEGRADATION VS. MILES

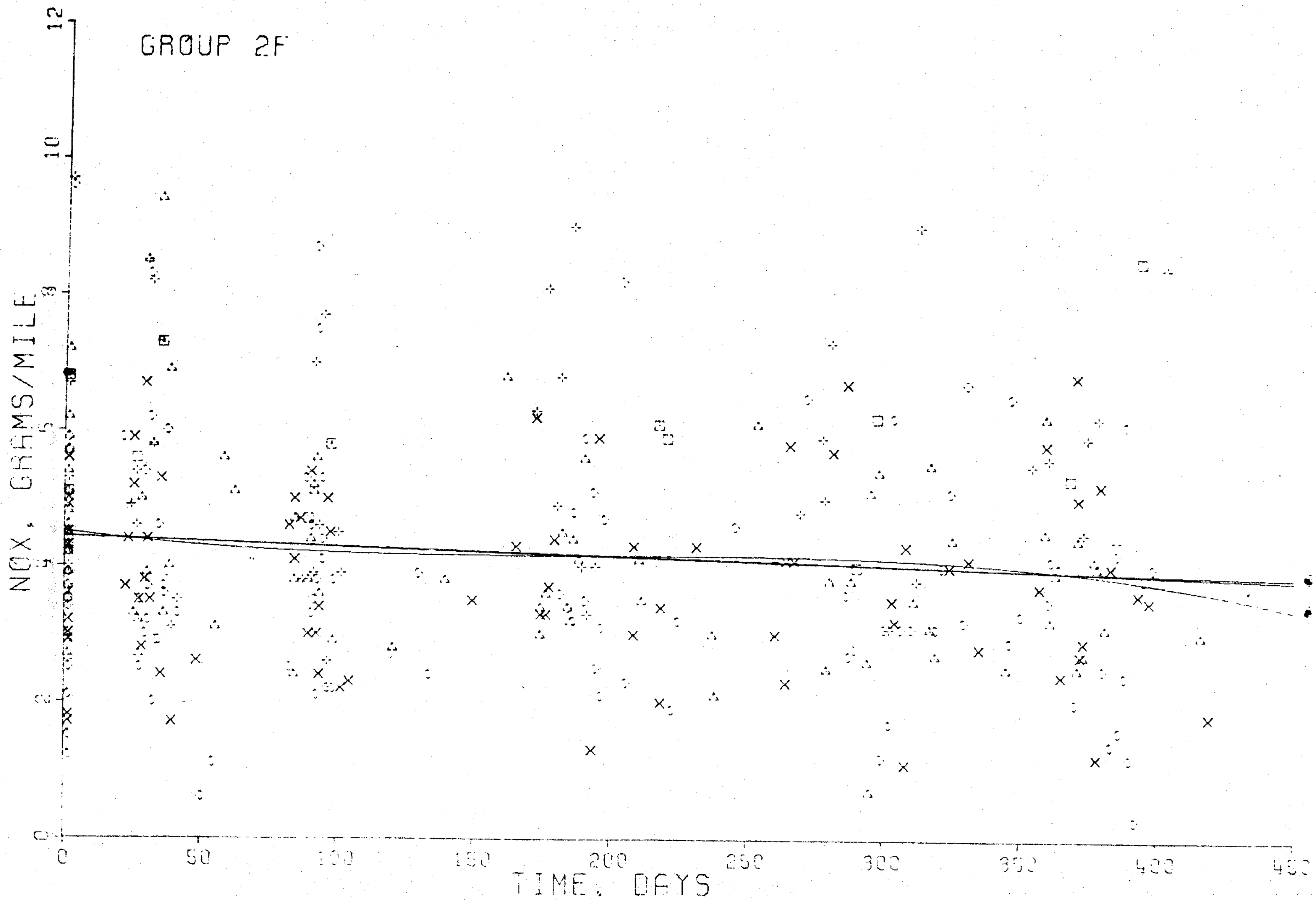


Figure 3-24. DEGRADATION VS. TIME

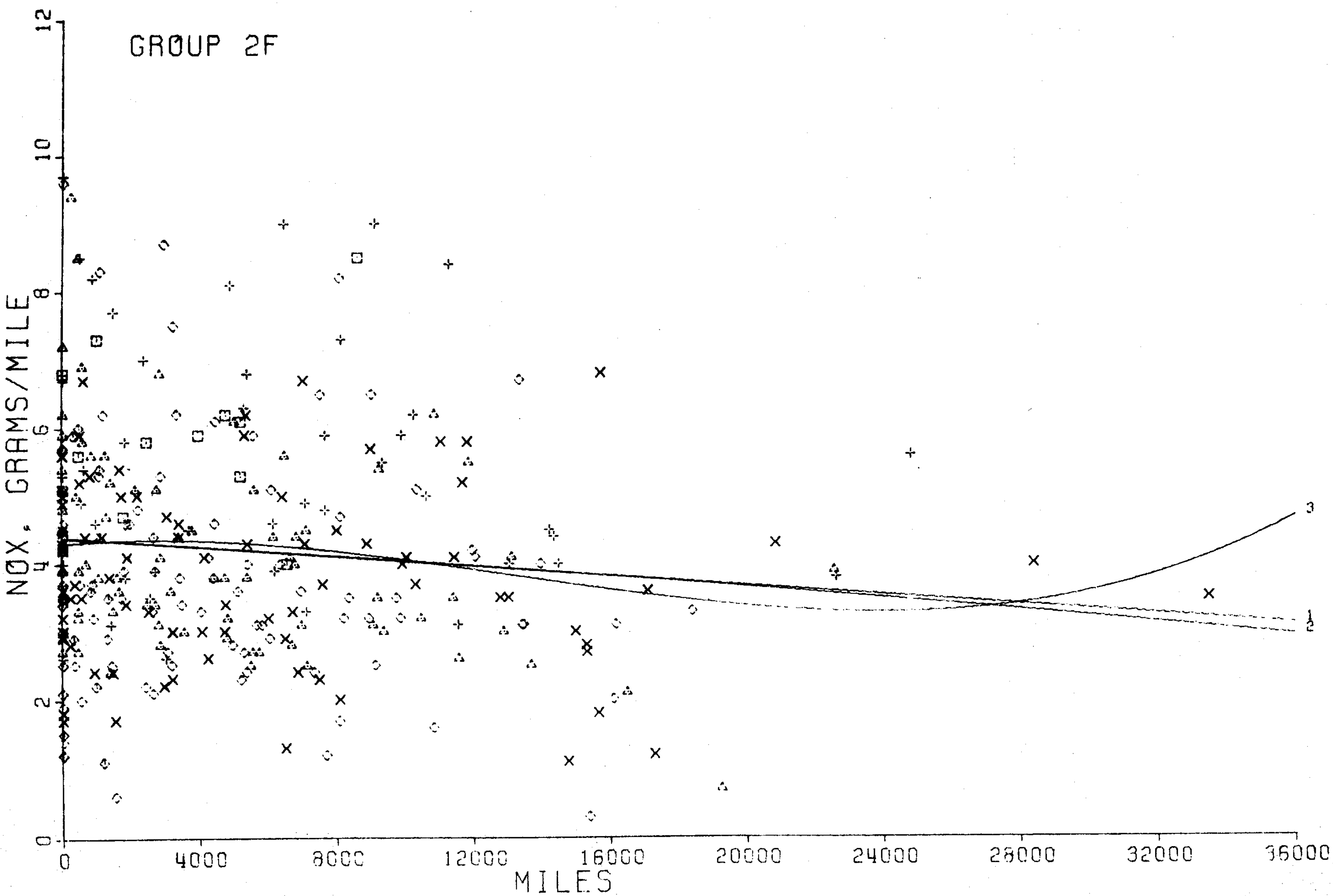


Figure 3-25. DEGRADATION VS. MILES

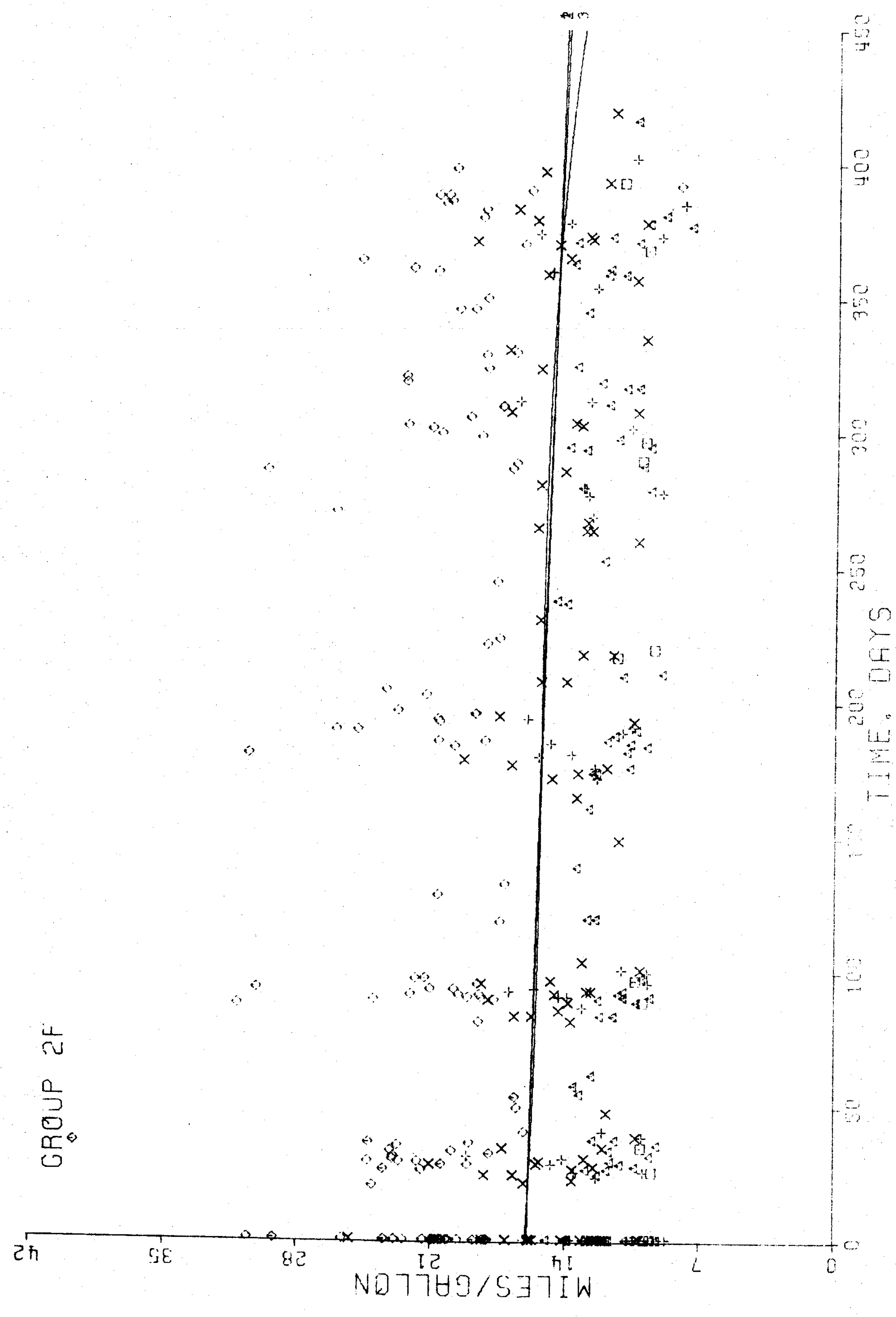


Figure 3-26. DEGRADATION VS. TIME

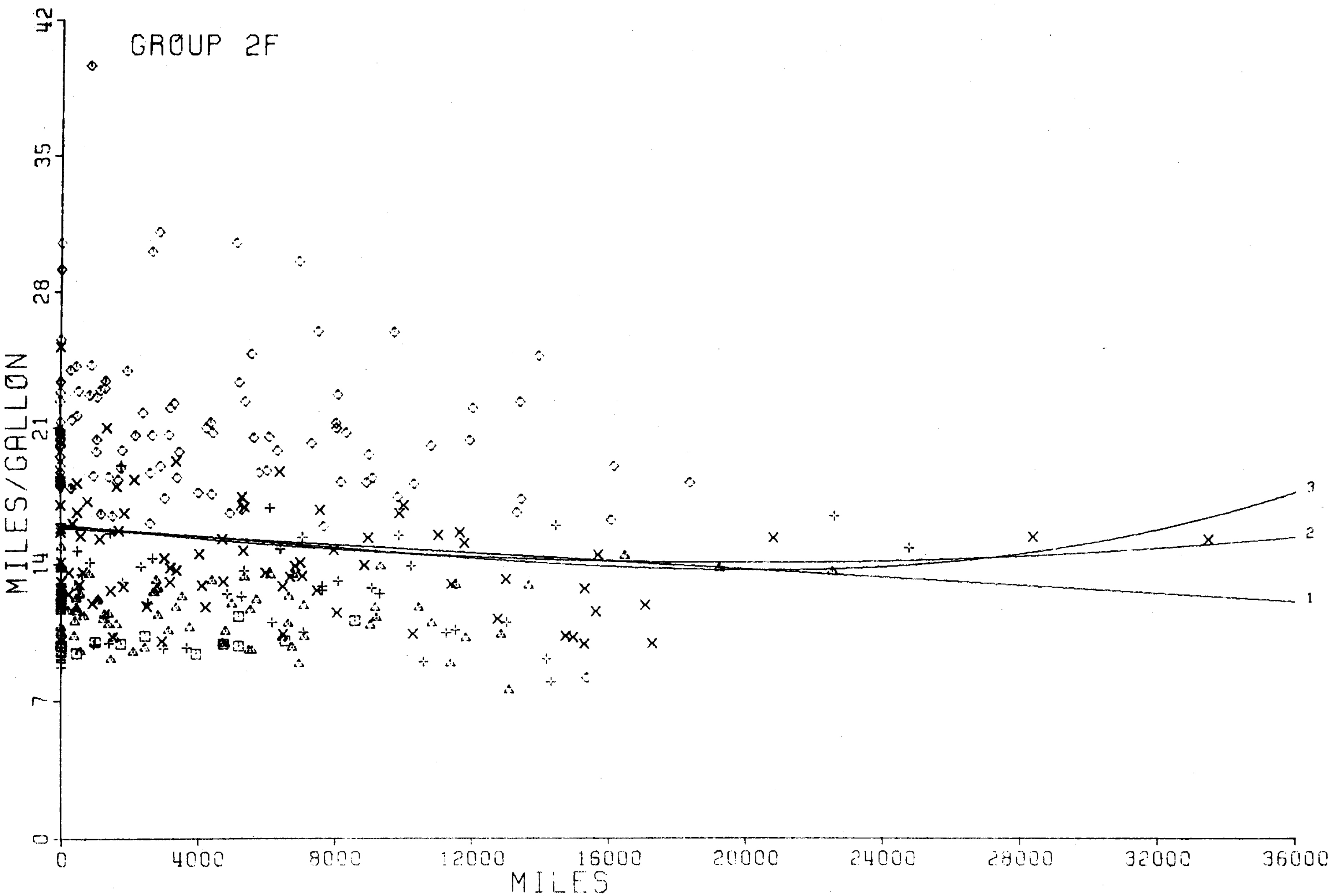


Figure 3-27. DEGRADATION VS. MILES

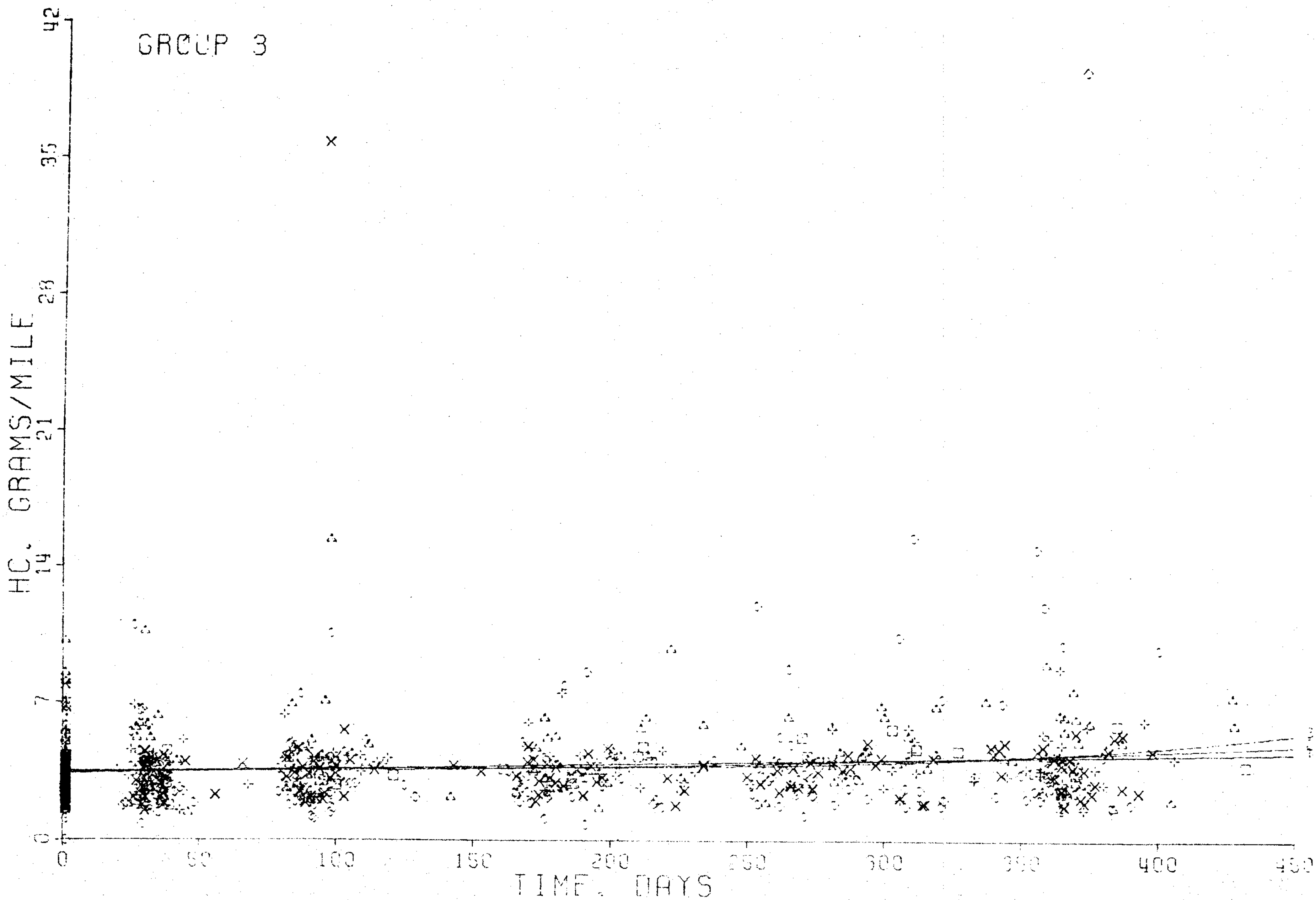


Figure 3-28. DEGRADATION VS. TIME

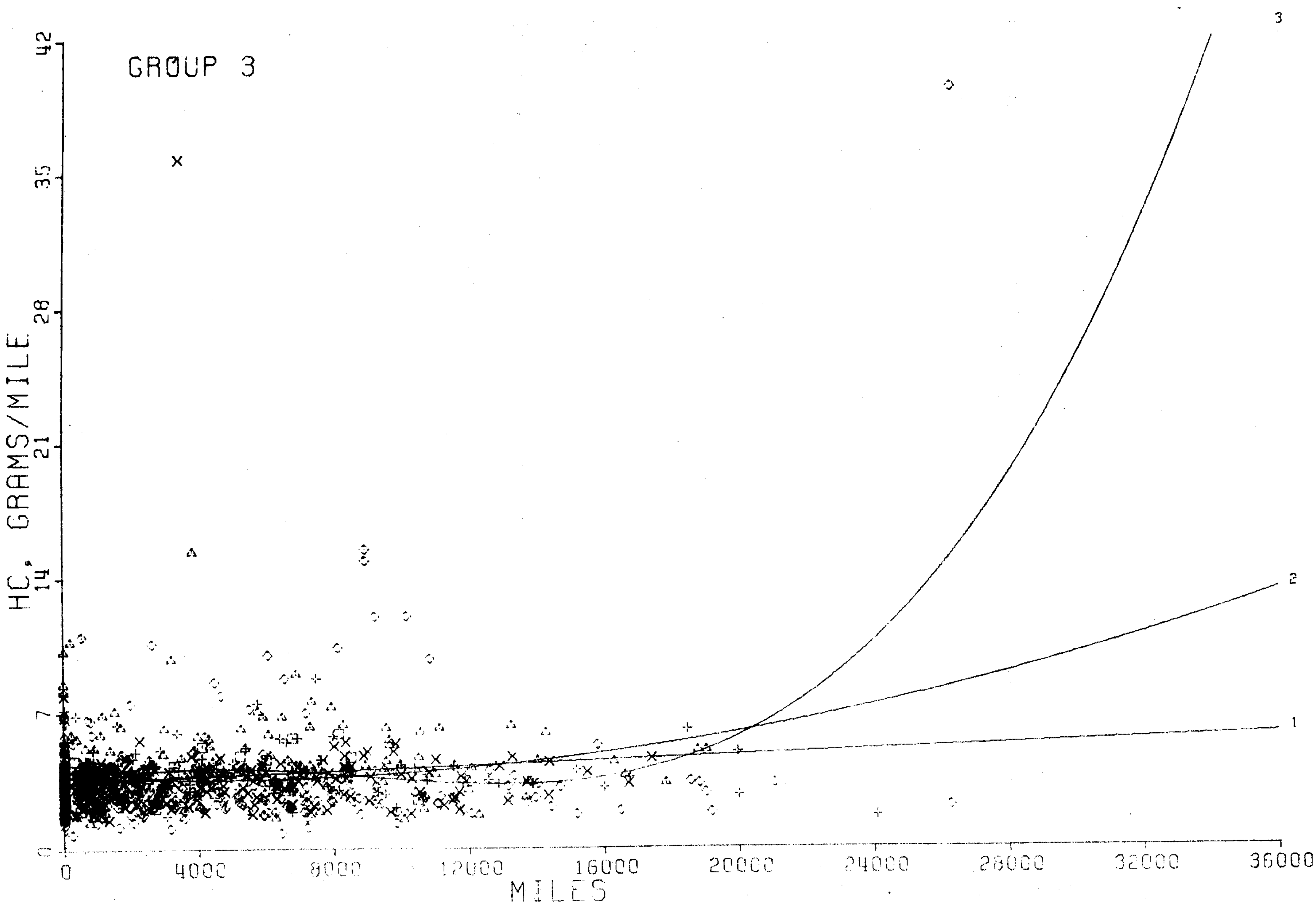


Figure 3-29. DEGRADATION VS. MILES

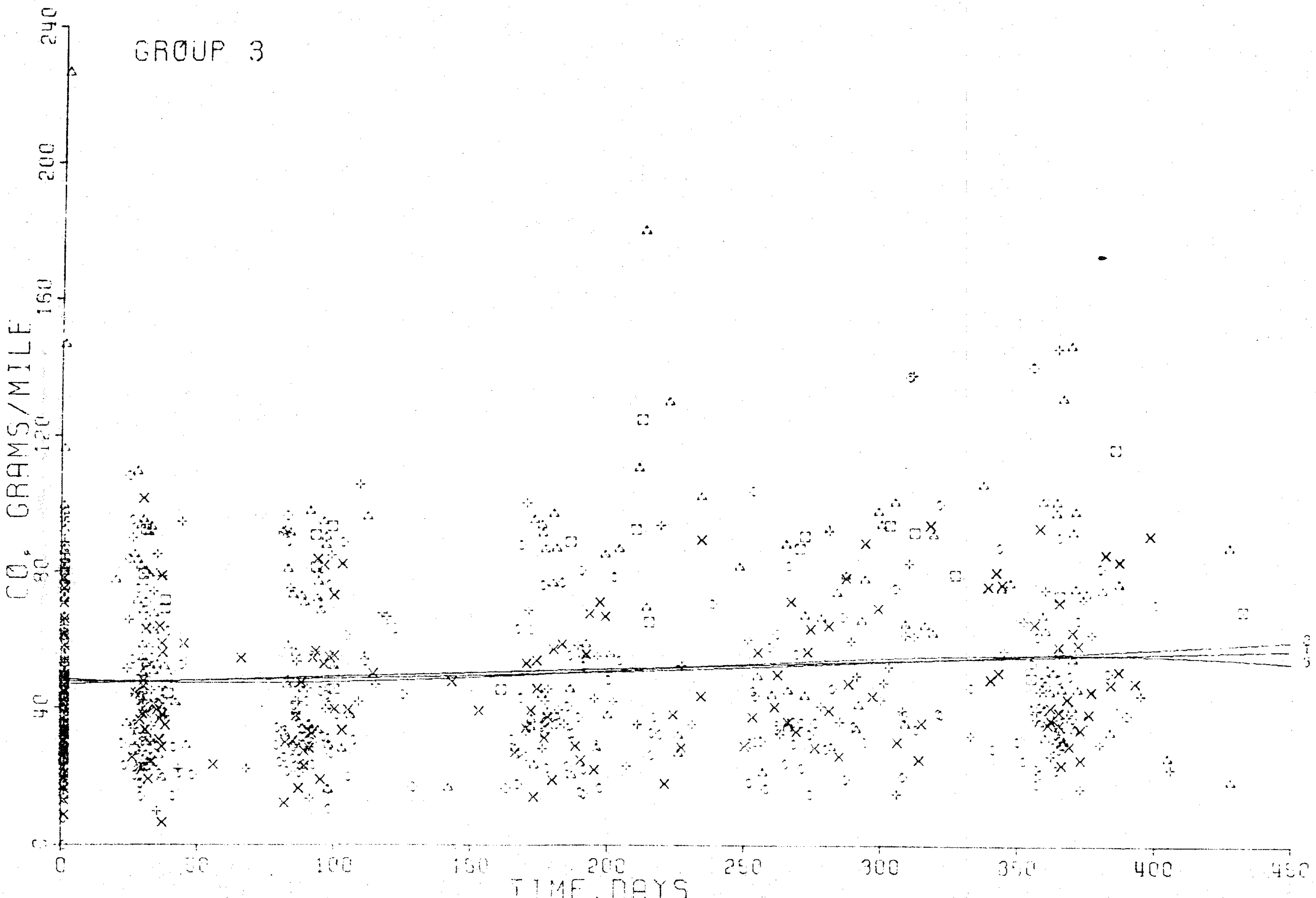


Figure 3-30. DEGRADATION VS. TIME

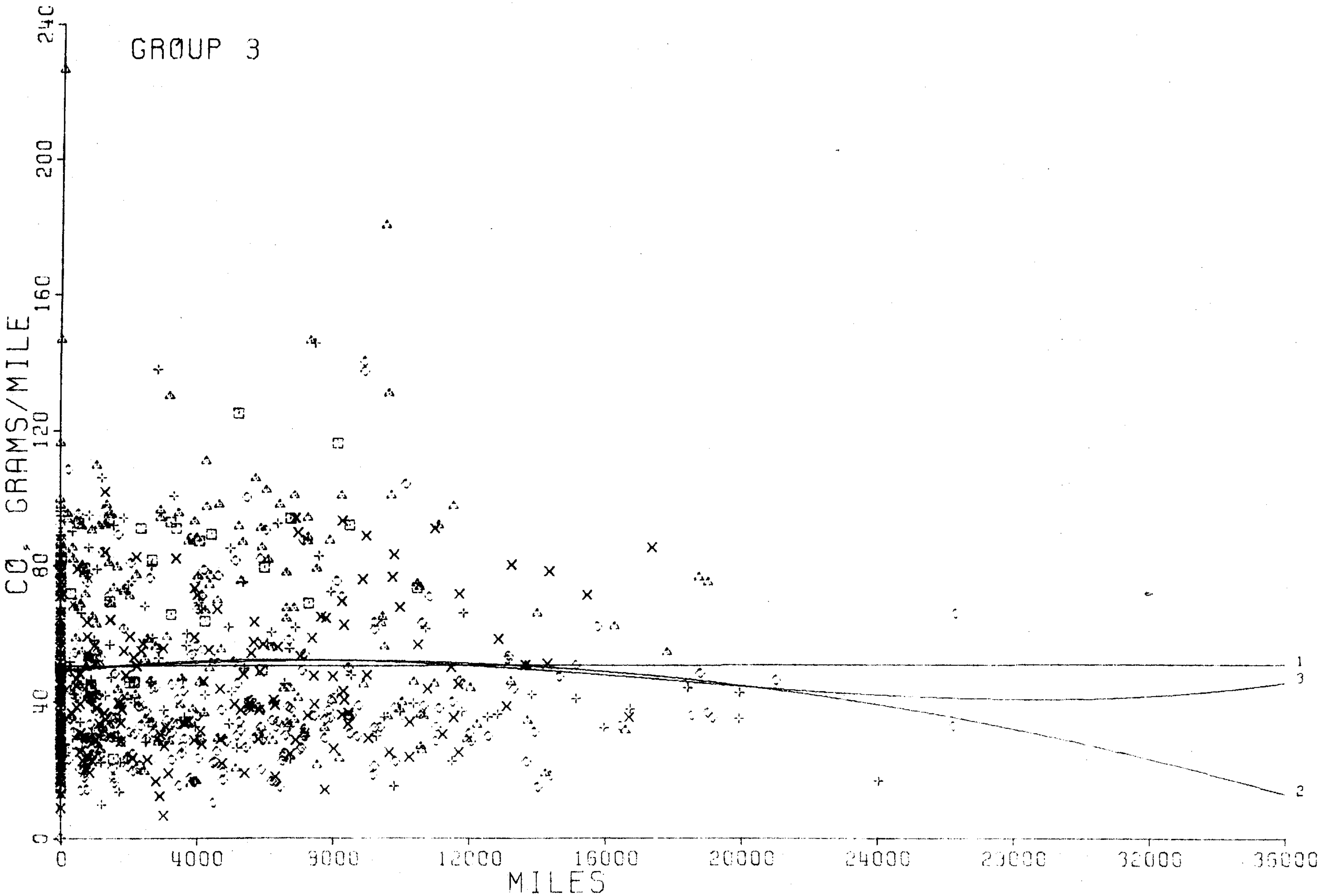


Figure 3-31. DEGRADATION VS. MILES

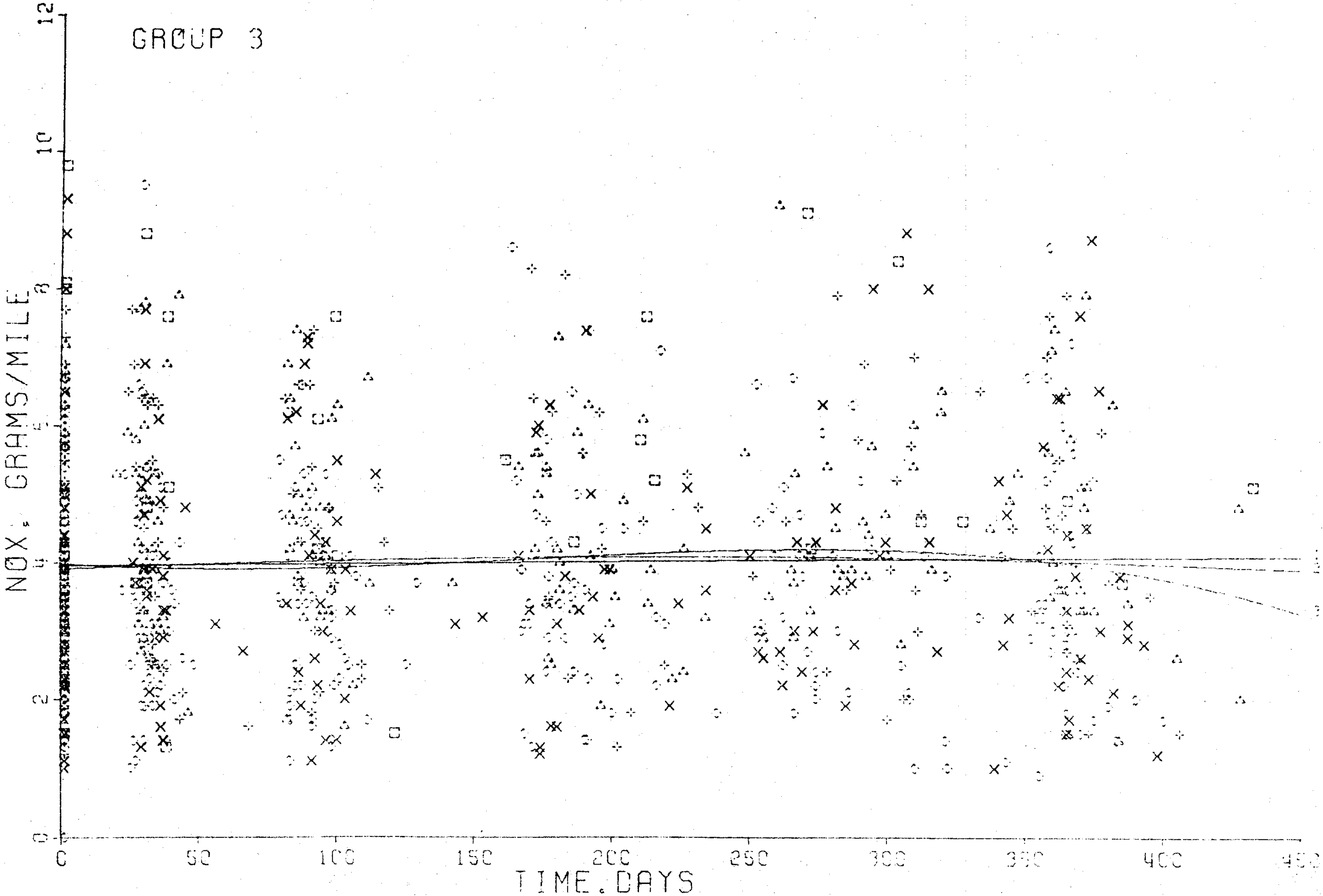


Figure 3-32. DEGRADATION VS. TIME

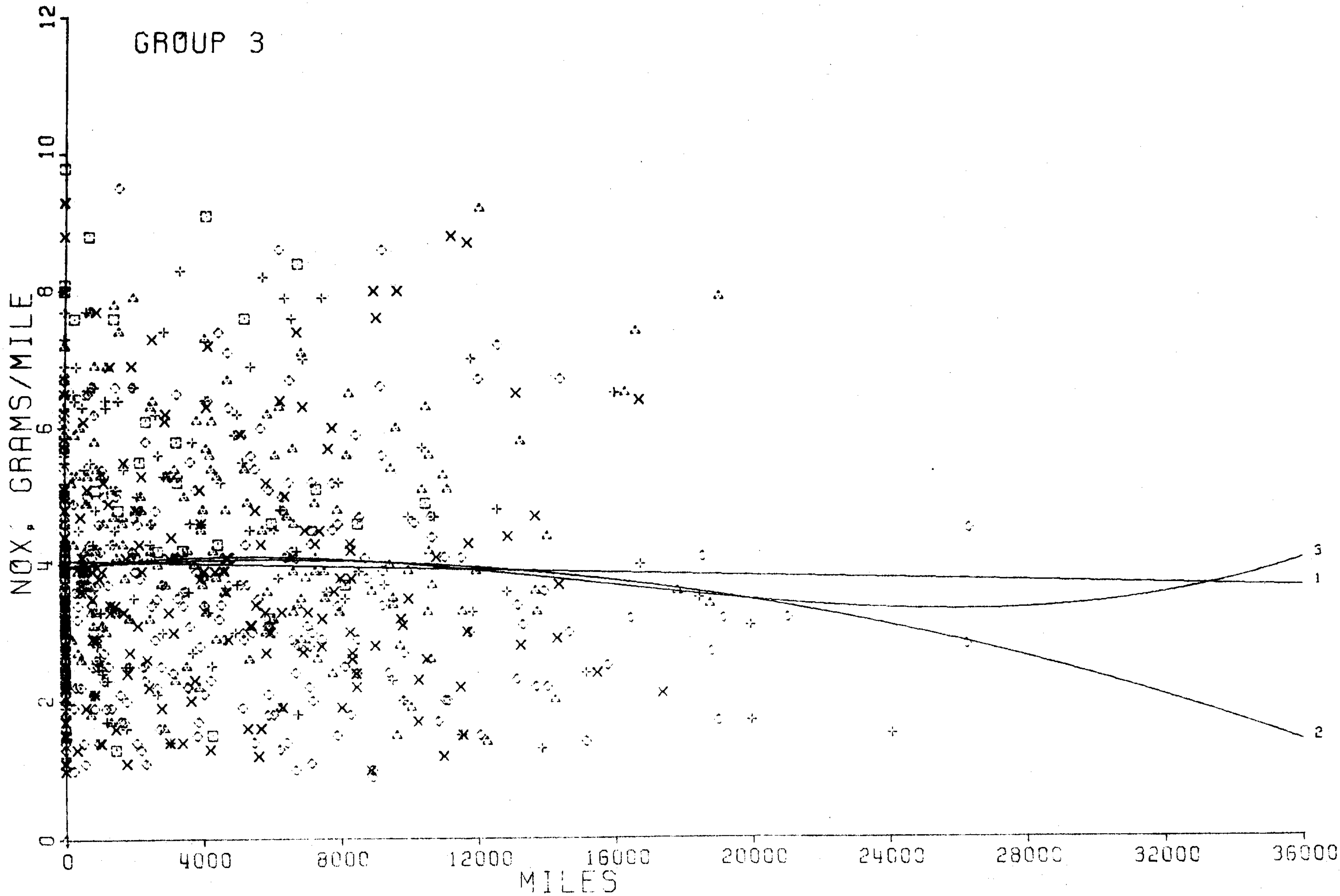


Figure 3-33. DEGRADATION VS. MILES

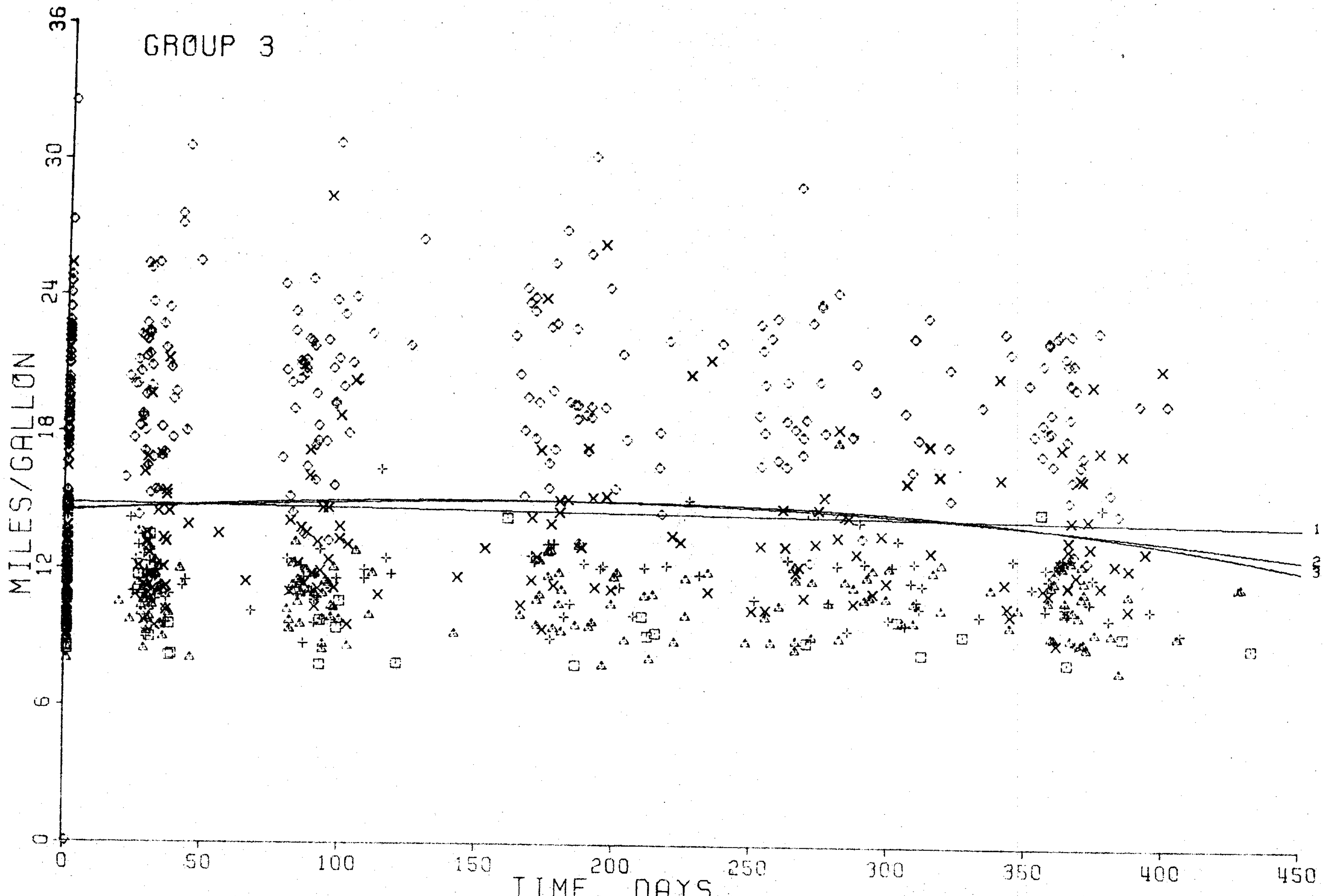


Figure 3-34. DEGRADATION VS. TIME

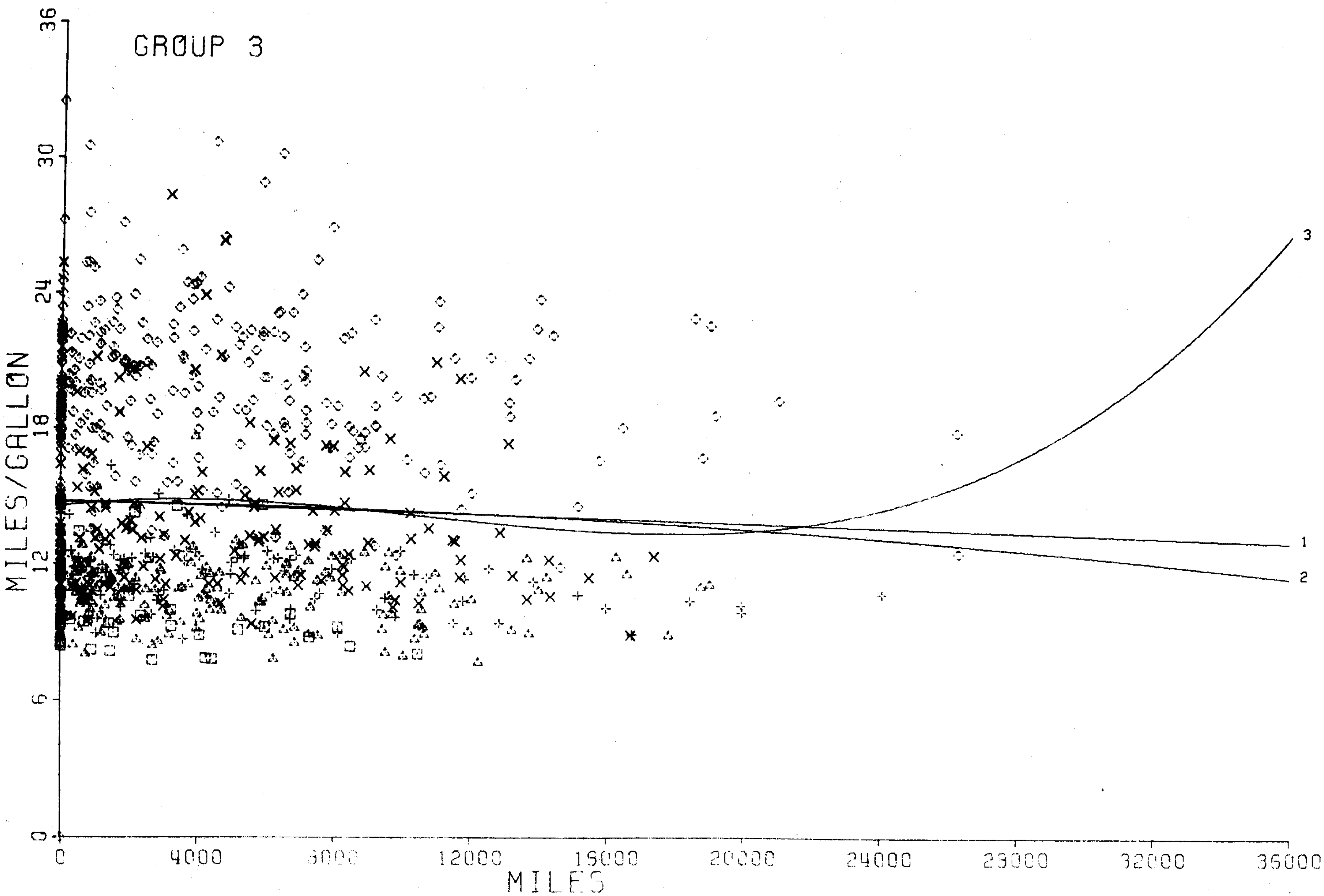


Figure 3-35. DEGRADATION VS. MILES

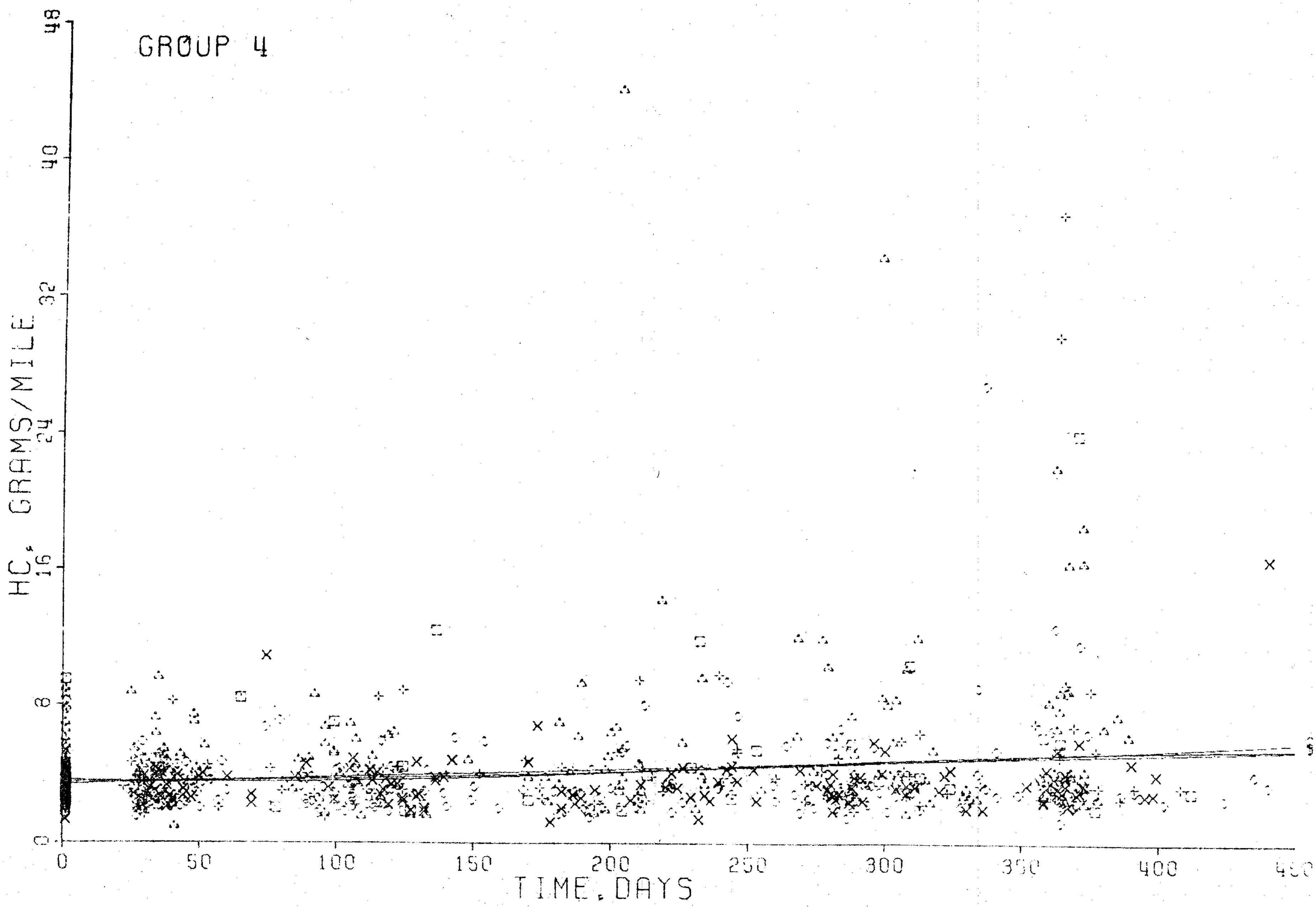


Figure 3-36. DEGRADATION VS. TIME

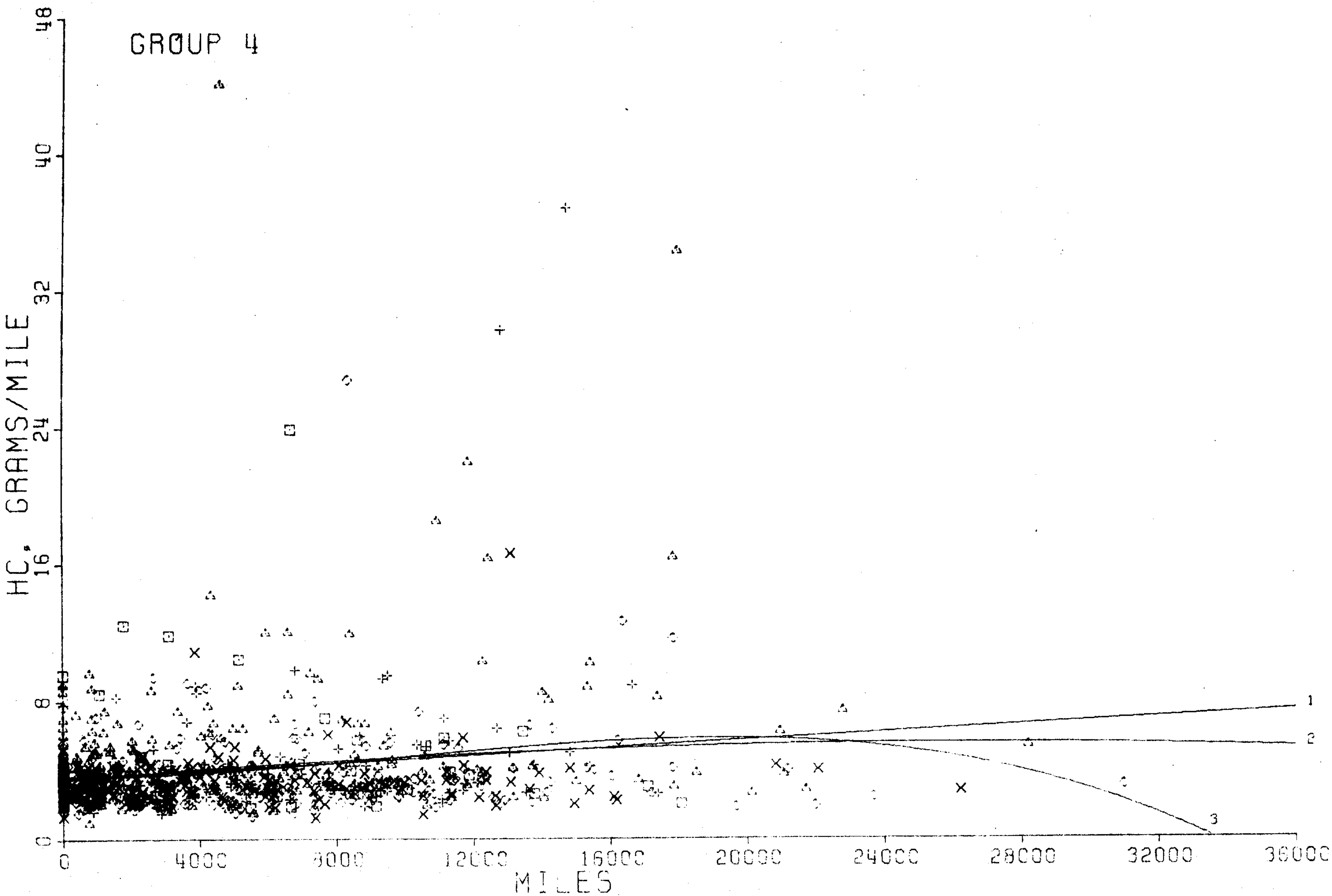


Figure 3-37. DEGRADATION VS. MILES

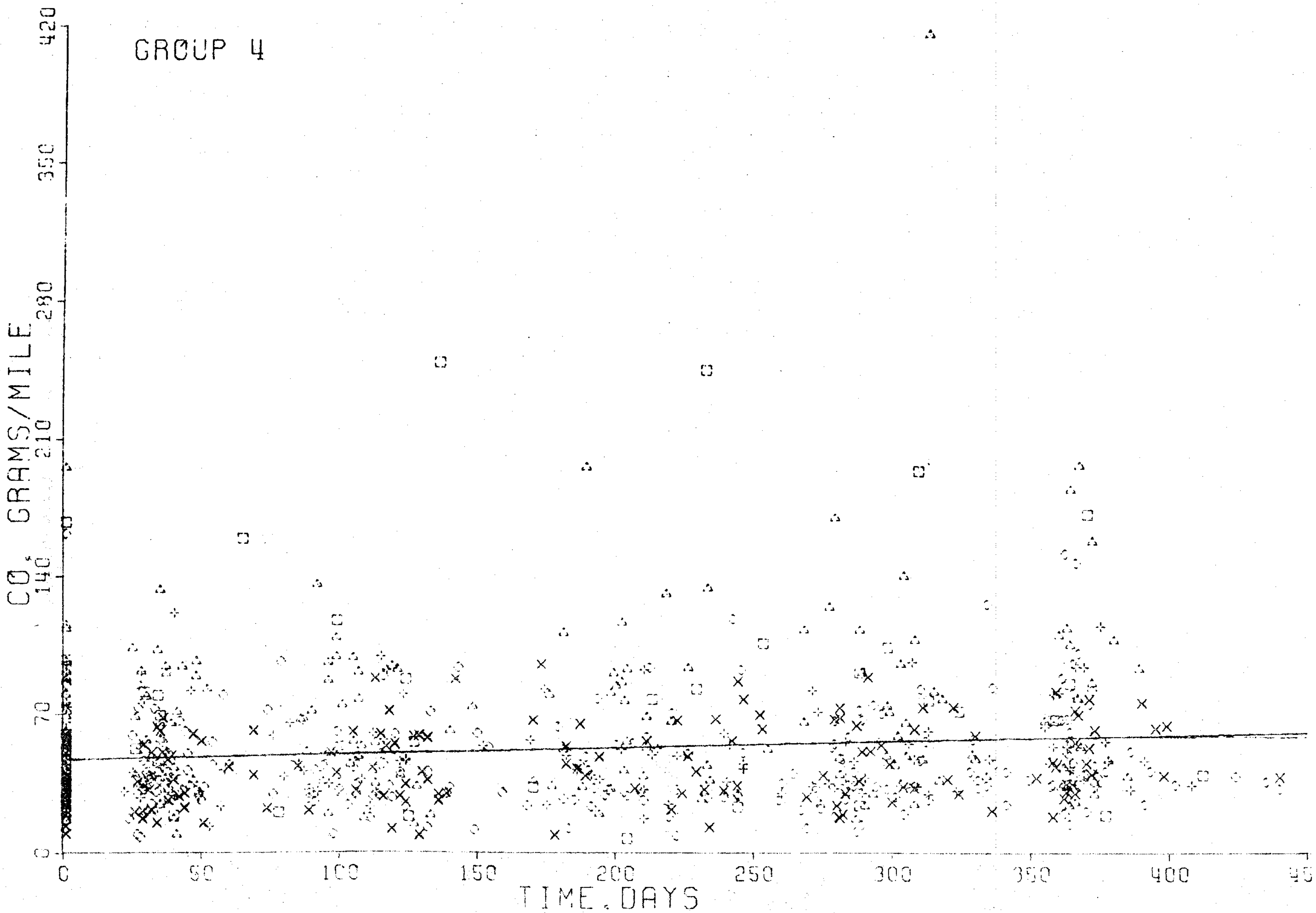


Figure 3-38. DEGRADATION VS. TIME

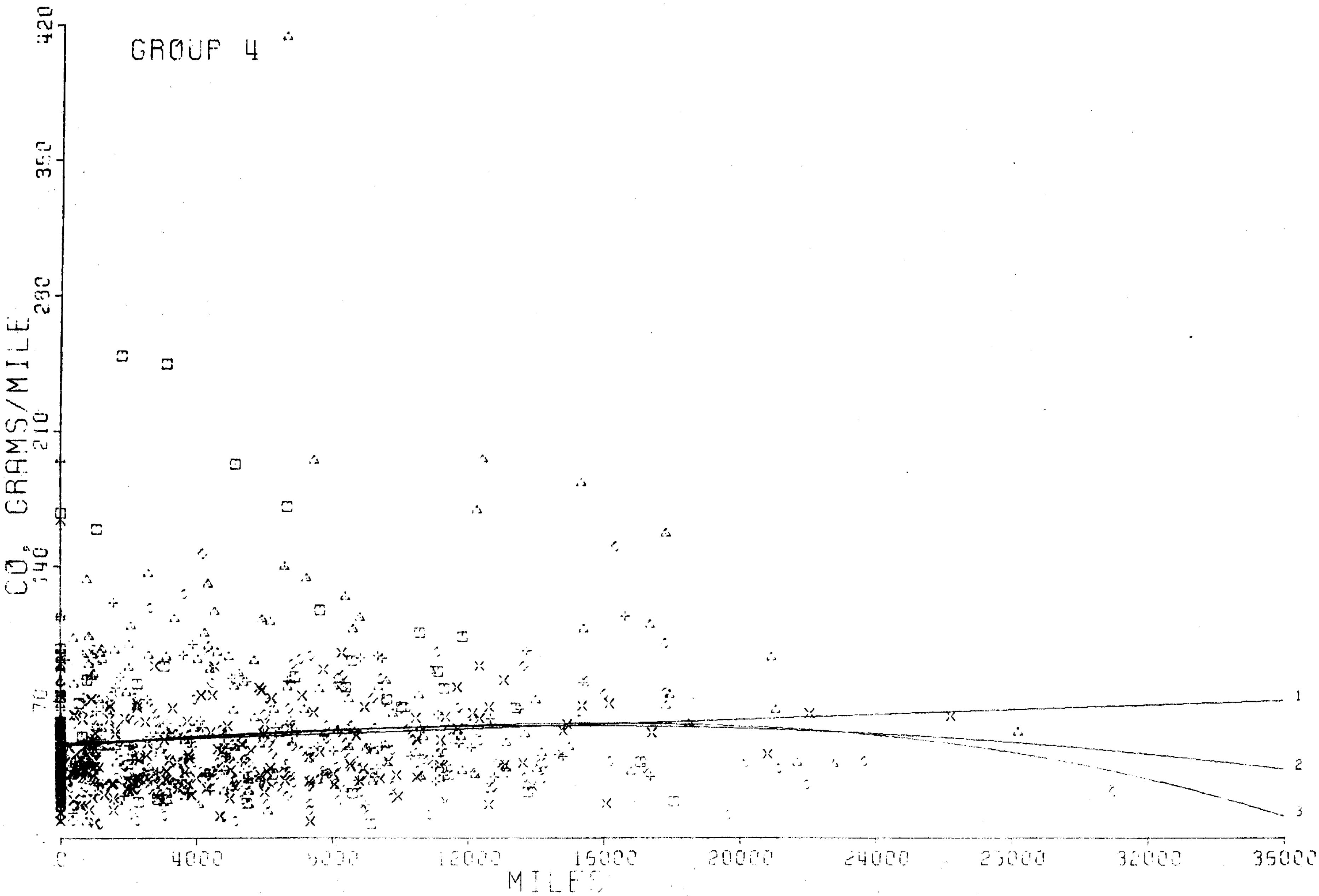


Figure 3-39. DEGRADATION VS. MILES

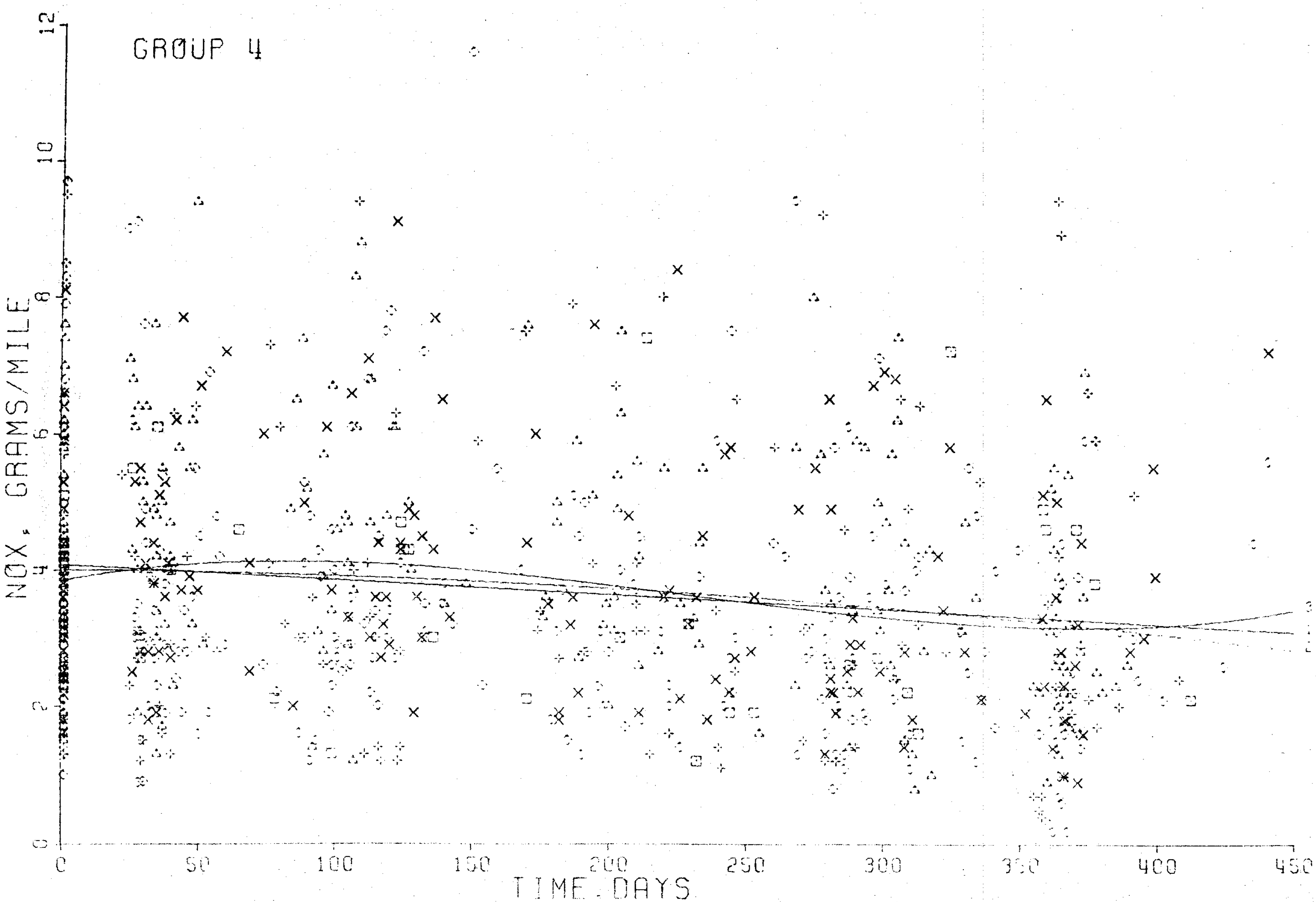


Figure 3-40. DEGRADATION VS. TIME

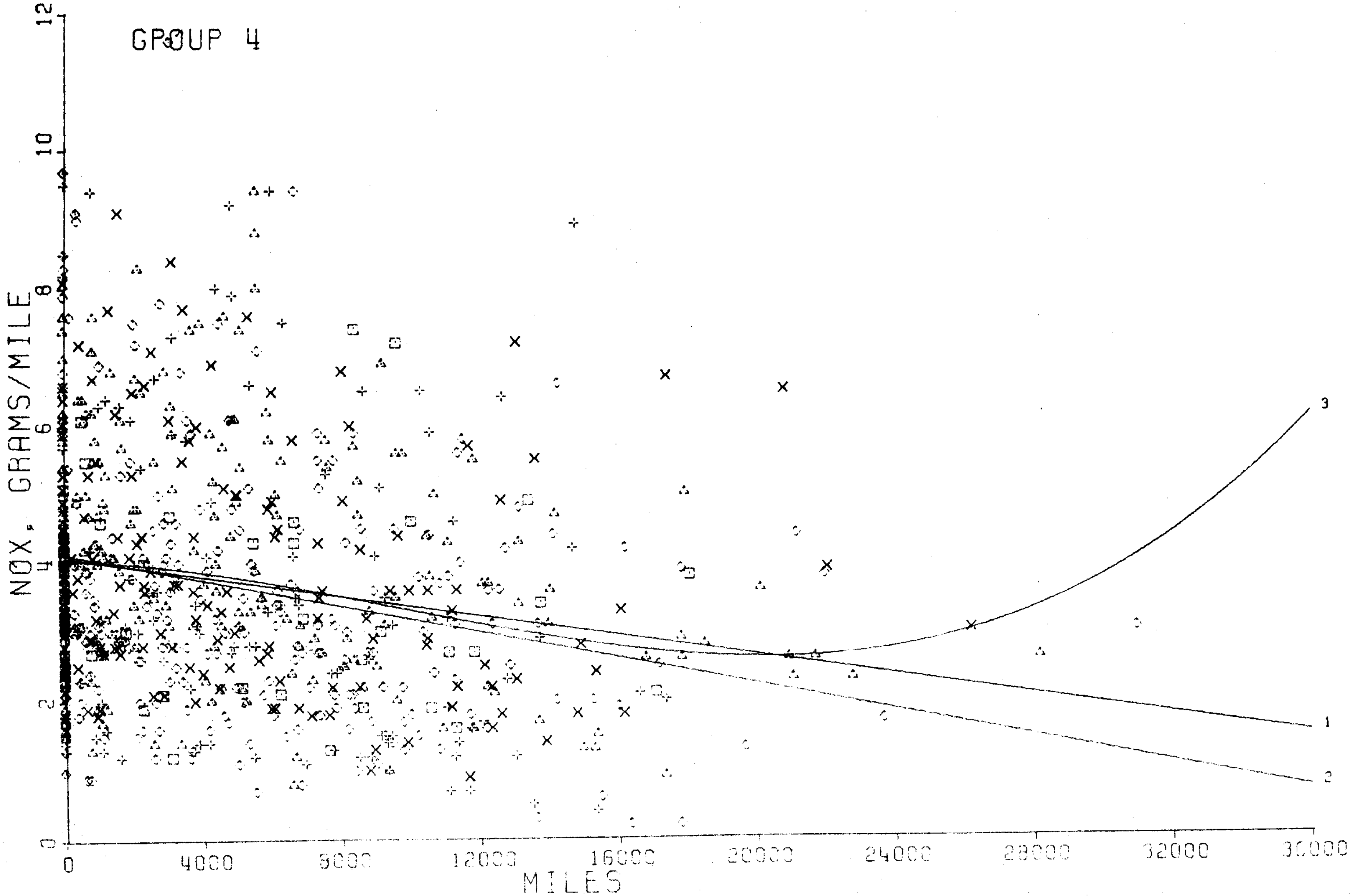


Figure 3-41. DEGRADATION VS. MILES

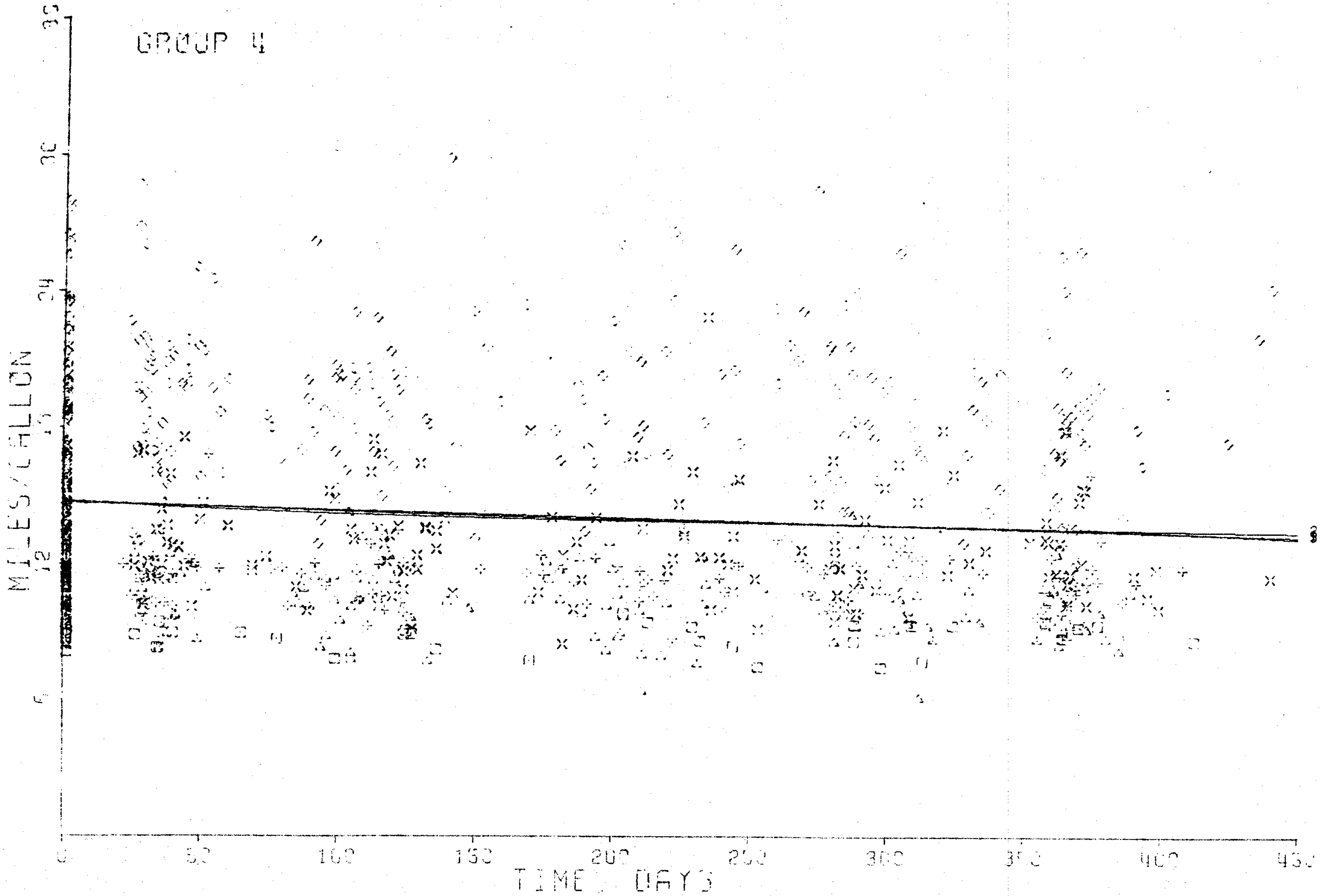


Figure 3-42. DEGRADATION VS. TIME

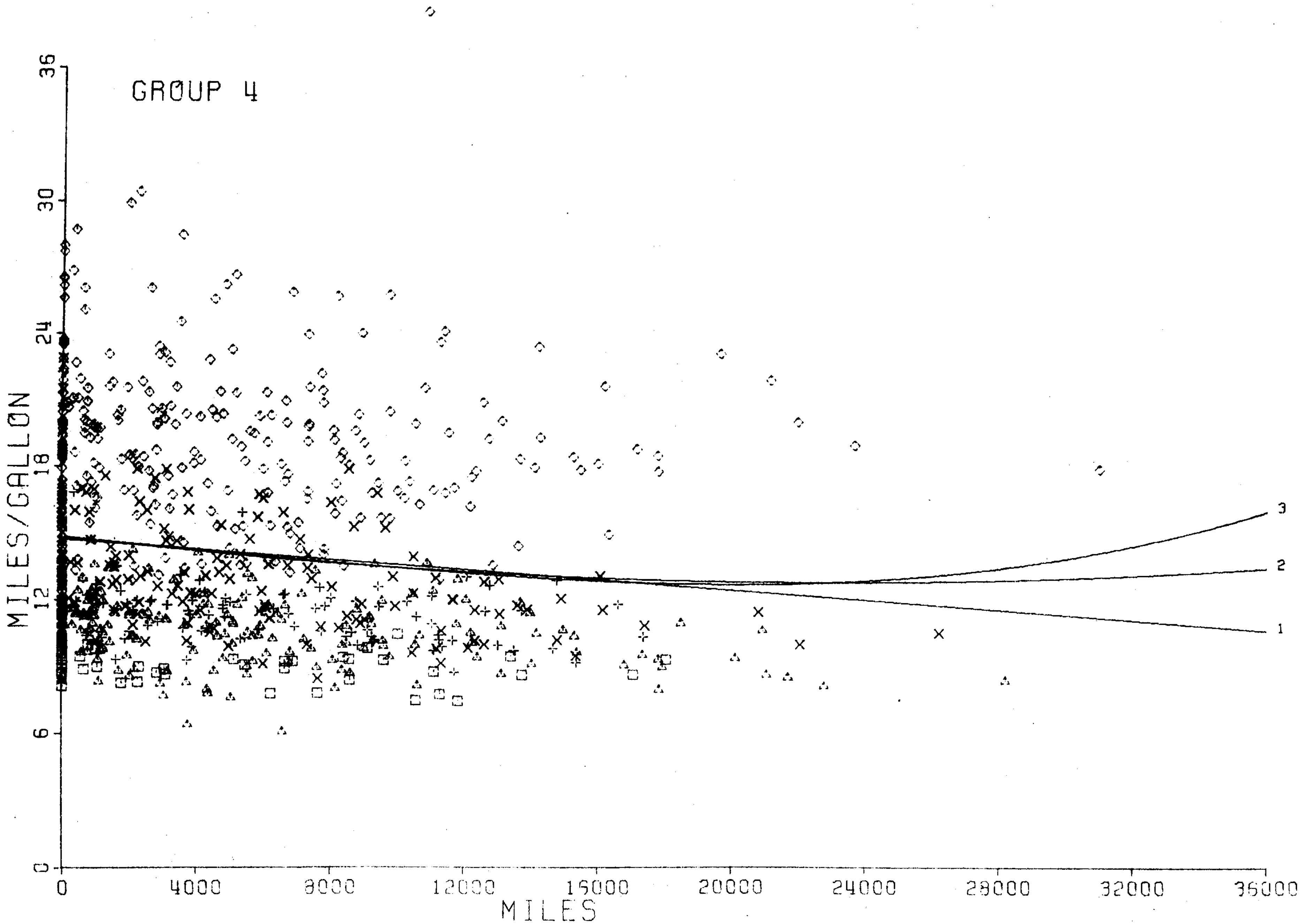


Figure 3-43. DEGRADATION VS. MILES

Section 4

RESULTS AND CONCLUSIONS

Various levels of maintenance were examined with respect to degradation emissions over a period of 1 year. As can be seen in the plots of degradation, a linear regression line appears to be the best fit for most of the cases examined.

It should be noted for the case of degradation as a function of miles driven, the three regression lines (1 linear, 2 quadrants, or 3 cubic) diverge at the high mileage point. The reason for this divergence is the lack of data points in this region.

A standard scale on the abscissa was used to accomodate all plots generated. As shown in Appendix A, late-model vehicles are driven more miles per year as would be expected.

4.1 RESULTS

Tables 4-1 and 4-2 present a summary of the stepwise regression analyses of Groups II, II Passed, II Failed, III and IV by pollutant. The linear, quadratic, and cubic regression coefficients and constants are presented along with the corresponding multiple R and standard error of estimate values. Table 4-1 shows the results of the stepwise regression for the independent variable x for times in days while Table 4-2 shows the results for distance driven in

Table 4-1. Stepwise Regression Summary (Time)

Group No.	Pollutant	Linear Terms $ax + b$				Quadratic Terms $ax^2 + bx + c$					Cubic Terms $ax^3 + bx^2 + cx + d$					
		$a(x10^{-2})$	b	Multiple R	Std. Error	$a(x10^{-4})$	$b(x10^{-2})$	c	Multiple R	Std. Error	$a(x10^{-6})$	$b(x10^{-4})$	$c(x10^{-2})$	d	Multiple R	Std. Error
II	HC	0.4352	3.303	0.1308	4.432	0.18270	-0.25290	3.568	0.1429	4.427	0.00948	0.1273	-0.1733	3.554	0.1430	4.430
II	CO	3.2710	48.470	0.1313	33.940	0.20330	2.51700	49.770	0.1316	33.860	-0.40450	2.5710	-0.8610	50.370	0.1330	33.970
II	NO_x	-0.1490	4.480	0.0801	2.553	0.06130	-0.37600	4.570	0.0869	2.553	-0.02040	0.1808	-0.5490	4.600	0.0879	2.555
II	MPG	-0.213	15.20	0.0604	4.839	-0.051	-0.024	15.13	0.0622	4.84	-0.080	0.416	-0.691	15.25	0.0678	4.84
IIP	HC	0.1871	3.288	0.1191	2.158	-0.02330	0.27030	3.255	0.1201	2.160	-0.08130	0.4625	-0.4349	3.383	0.1370	2.158
IIP	CO	2.2720	50.350	0.0905	34.590	-0.73600	5.02100	49.290	0.0956	34.620	-0.88990	4.5730	-2.7030	50.690	0.1058	34.620
IIP	NO_x	-0.1579	4.521	0.0711	3.064	0.09740	-0.52160	4.661	0.0848	3.065	-0.01560	0.1903	-0.6566	4.686	0.0852	3.068
IIP	MPG	-0.088	14.65	0.0254	4.77	-0.057	0.124	14.57	0.0308	4.775	-0.088	0.468	-0.639	14.71	0.0448	4.778
IIF	HC	0.719	3.318	0.1567	6.188	0.53000	-1.23300	4.093	0.1941	6.156	0.38500	-1.6590	1.7980	3.559	0.2118	6.142
IIF	CO	4.5540	48.230	0.1848	33.080	1.70700	-1.72900	50.730	0.1971	33.050	1.27700	-5.5570	8.3300	48.960	0.2040	33.050
IIF	NO_x	-0.1360	4.431	0.1093	1.694	0.00710	-0.16240	4.442	0.1094	1.696	-0.04790	0.2798	-0.5400	4.508	0.1161	1.697
IIF	MPG	-0.398	15.96	0.1104	4.892	-0.026	-0.303	15.93	0.1106	4.90	-0.080	0.430	-0.934	16.04	0.1129	4.90
III	HC	0.2430	3.388	0.1325	2.421	0.07030	-0.00987	3.484	0.1377	2.421	0.05530	-0.2396	0.4113	3.412	0.1410	2.421
III	CO	2.3150	46.890	0.1160	26.380	0.47700	0.59900	47.550	0.1184	26.390	-0.61300	3.9070	-4.0640	48.350	0.1223	26.400
III	NO_x	0.0280	3.958	0.0213	1.757	-0.03690	0.16100	3.907	0.0348	1.757	-0.05990	0.2985	-0.2950	3.986	0.0572	1.757
III	MPG	-0.175	14.85	0.0476	4,878	-0.263	0.773	14.49	0.0851	4.869	-0.045	-0.0113	0.431	14.55	0.860	4.872
IV	HC	0.4590	3.374	0.1831	3.346	0.08290	0.15550	3.497	0.1864	3.346	-0.05560	0.4265	-0.3774	3.602	0.1902	3.346
IV	CO	3.1410	46.550	0.1270	33.300	-0.04830	3.31800	46.480	0.1270	33.320	-0.26940	1.6180	0.7335	46.990	0.1283	33.340
IV	NO_x	-0.2220	4.080	0.1616	1.840	-0.04950	-0.04070	4.007	0.1660	1.840	0.08250	-0.5600	0.7510	3.850	0.1947	1.831
IV	MPG	-0.335	14.68	0.098	4.616	0.035	-0.465	14.73	0.0987	4.619	-0.0335	0.243	-0.786	14.80	0.1000	4.621

Table 4-2. Stepwise Regression Summary (Miles)

Group No.	Pollutant	Linear Terms $ax + b$: $a(x10^{-4})$	b	Multiple R	Std. Error	Quadratic Terms $ax^2 + bx + c$: $a(x10^{-8})$	$b(x10^{-4})$	c	Multiple R	Std. Error	Cubic Terms $ax^3 + bx^2 + cx + d$: $a(x10^{-12})$	$b(x10^{-8})$	$c(x10^{-4})$	d	Multiple R	Std. Error
II	HC	0.9616	3.518	0.1062	4.445	-0.3066	1.458	3.431	0.1096	4.446	-0.6089	1.896	-0.2951	3.601	0.1220	4.443
II	CO	3.714	52.80	0.0535	34.18	-7.431	15.73	50.68	0.1012	34.08	-0.586	-5.311	14.05	50.84	0.1014	34.10
II	NO_x	-0.634	4.543	0.1222	2.542	0.1149	-0.820	4.576	0.1234	2.543	0.1294	-0.353	-0.448	4.539	0.1250	2.544
II	MPG	-0.583	15.14	0.0593	4.84	0.424	-1.269	15.26	0.0687	4.84	0.176	-0.213	-0.762	15.22	0.0702	4.843
IIP	HC	0.395	3.395	0.0819	2.166	-0.644	1.261	3.276	0.1086	2.163	-0.164	-0.212	0.993	3.297	0.1095	2.165
IIP	CO	4.506	51.83	0.0584	34.66	-9.055	16.69	50.10	0.0858	34.65	-0.882	-6.735	15.25	50.21	0.0859	34.69
IIP	NO_x	-0.945	4.689	0.1387	3.042	0.097	-1.075	4.707	0.1389	3.046	-0.170	0.544	-1.353	4.728	0.1392	3.050
IIP	MPG	-0.173	14.60	0.0164	4.771	0.895	-1.378	14.77	0.0481	4.771	1.134	-2.080	0.477	14.63	0.0641	4.773
IIF	HC	1.366	3.784	0.1184	6.221	-0.617	2.508	3.553	0.128	6.223	-1.103	3.655	-1.105	3.934	0.1525	6.211
IIF	CO	2.844	54.04	0.0459	33.63	-7.737	17.17	51.14	0.1232	33.46	-1.474	-2.030	12.35	51.65	0.1249	33.50
IIF	NO_x	-0.355	4.390	0.1132	1.693	-0.0262	-0.3068	4.380	0.1135	1.695	0.2211	-0.8819	0.417	4.304	0.1288	1.695
IIF	MPG	-1.045	15.85	0.1153	4.890	0.499	-1.969	16.03	0.1258	4.891	0.2927	-0.634	-1.0111	15.93	0.1289	4.897
III	HC	0.659	3.464	0.1244	2.424	0.962	-0.790	3.708	0.1754	2.406	2.564	-6.700	4.396	3.261	0.2944	2.334
III	CO	0.232	50.25	0.0040	26.56	-4.923	7.645	49.00	0.0583	26.53	2.197	-11.49	12.09	48.62	0.0614	26.55
III	NO_x	-0.112	4.049	0.0294	1.757	-0.291	0.326	3.975	0.0597	1.755	0.176	-0.817	0.682	3.944	0.0640	1.756
III	MPG	-0.495	14.80	0.0468	4.878	-0.200	-0.194	14.75	0.0485	4.881	1.006	-3.208	1.842	14.58	0.0680	4.878
IV	HC	1.093	3.567	0.1672	3.356	-0.307	1.608	3.468	0.1709	3.356	-0.655	1.902	-0.0907	3.636	0.1831	3.350
IV	CO	6.121	48.56	0.0949	33.42	-4.872	14.30	46.98	0.1108	33.38	-2.0176	1.931	9.069	47.50	0.1127	33.40
IV	NO_x	-0.729	4.088	0.2036	1.826	0.139	-0.962	4.133	0.2057	1.826	0.3014	-0.878	-0.181	4.056	0.2130	1.824
IV	MPG	-1.134	14.71	0.1273	4.601	0.3913	-1.791	14.837	0.1315	4.601	0.212	-0.323	-1.241	14.78	0.1325	4.603

miles. Therefore, for a 1 year period, x corresponds to 365 days for time and 12,000 miles for distance traveled.

Tables 4-3 and 4-4 present the results of the linear regression for 1 year and 12,000 miles period. The last column lists the percent change in emission and fuel economy for the various groups. As might be expected, the manufacturer's specification group (Group III) experienced the least degradation of HC and CO emissions. Groups II and IV experienced the greatest degradation in HC and CO.

As a matter of interest, an integration of the linear, quadratic, and cubic equations was performed in order to determine the area under the curve over the 1 year interval. The following integrations were obtained:

Linear:

$$\int_0^{365} (ax + b)\,dx = \frac{ax^2}{2} + bx \Big|_0^{365}$$

$$\text{Area}_{(1)} = 6.66\text{x}10^4 a + 365b$$

Quadratic:

$$\int_0^{365} (ax^2 + bx + c)\,dx = \frac{ax^3}{3} + \frac{bx^2}{2} + cx \Big|_0^{365}$$

$$\text{Area}_{(2)} = 1.621\text{x}10^7 a + 6.66\text{x}10^4 b + 365c$$

Cubic:

$$\int_0^{365} (ax^3 + bx^2 + cx + d)\,dx = \frac{ax^4}{4} + \frac{bx^3}{3} + \frac{cx^2}{2} + dx \Big|_0^{365}$$

$$\text{Area}_{(3)} = 4.437\text{x}10^9 a + 1.621\text{x}10^7 b + 6.66\text{x}10^4 c + 365d$$

Table 4-3. One Year Emission Degradation By Group In Percent (Time)

Group No.	Pollutant	Linear Terms Coefficient a(x10^{-2})	Linear Terms Constant b	ax Where x = 365	% Increase At 12 Months
II	HC	0.4252	3.303	1.552	47
II	CO	3.271	49.47	11.94	24
II	NO_x	-0.149	4.48	-0.544	-12
II	MPG	-0.213	15.2	-0.777	-5.1
IIP	HC	0.1871	3.288	0.683	21
IIP	CO	2.272	50.35	8.30	16.5
IIP	NO_x	-0.1579	4.521	-0.58	-12.8
IIP	MPG	-0.088	14.65	-0.321	-2.2
IIF	HC	0.719	3.318	2.624	79
IIF	CO	4.554	48.23	16.62	34.5
IIF	NO_x	-0.136	4.431	-0.4964	-11.2
IIF	MPG	-0.398	15.96	-1.428	-8.9
III	HC	0.243	3.388	0.887	26.2
III	CO	2.315	46.89	8.44	18
III	NO_x	0.028	3.958	0.102	2.6
III	MPG	-0.175	14.85	-0.639	-4.3
IV	HC	0.457	3.374	1.67	49.5
IV	CO	3.141	46.55	11.46	24.6
IV	NO_x	-0.222	4.080	-0.81	-19.9
IV	MPG	-0.335	14.68	-1.223	-8.3

Table 4-4. One Year Emission Degradation By Group In Percent (Miles)

Group No.	Pollutant	Linear Terms: Coefficient $a(x10^{-4})$	Linear Terms: Constant b	ax Where x = 12,000	% Increase At 12,000 Miles
II	HC	0.9616	3.518	1.154	32.8
II	CO	3.714	52.80	4.46	8.5
II	NO_x	-0.634	4.543	-0.761	-16.8
II	MPG	-0.583	15.14	-0.700	-4.6
IIP	HC	0.395	3.395	0.474	14.0
IIP	CO	4.506	51.83	5.41	10.5
IIP	NO_x	-0.945	4.689	-1.134	-24.2
IIP	MPG	-0.173	14.60	-0.208	-1.4
IIF	HC	1.366	3.784	1.639	43.3
IIF	CO	2.844	54.04	3.413	6.3
IIF	NO_x	-0.355	4.39	-0.426	-9.7
IIF	MPG	-1.045	15.85	-1.254	-7.9
III	HC	0.659	3.464	0.791	22.8
III	CO	0.232	50.35	0.278	0.6
III	NO_x	-0.112	4.049	-0.134	-3.3
III	MPG	-0.495	14.80	-0.594	-4.0
IV	HC	1.093	3.567	1.312	36.8
IV	CO	6.121	48.56	7.345	15.1
IV	NO_x	-0.729	4.088	-0.875	-21.4
IV	MPG	-1.134	14.71	-1.361	-9.3

Table 4-5 shows the results of the integrations for each case considered using the values of the coefficients and constants listed in Table 4-1. As can be seen, the areas for the linear case closely approximate the quadratic and cubic regressions.

In order to compare the various maintenance groups with respect to cost, effectiveness, and cost-effectiveness, a reference group for effectiveness was needed. To arrive at this reference group, the as-received emissions of all groups was averaged. The reference group cost and degradation used was that exhibited by the control group. Table 4-6 shows the assumed values for the reference group. In addition, a reference group was generated for Group II failed.

Table 4-7 shows the difference in emissions for one average vehicle in each maintenance group and the reference group, the difference in group service costs from the reference group, and the cost-effectiveness ratio for the period of 1 year assuming an average mileage of 12,000 miles.

As can be seen, the short-cycle emission test (Group II) is clearly the most cost-effective. These types of programs identify gross emitters and only require vehicles which require attention to obtain the necessary repair. However, from strictly an effectiveness point of view, Group III obtained the maximum benefit in HC and CO reductions.

4.2 CONCLUSIONS

Various levels of maintenance were examined with respect to degradation in emissions over a period of 1 year. Significant degradation levels are encountered for both HC and CO during the 1-year interval, as seen from the stepwise regressions, a linear fit appears to suffice for most cases

Table 4-5. Area Under Curve for One Year Period

Group No.	Pollutant	Area Under Curve For x = 365 Days: Linear (gms/mile x yr)	Quadratic (gms/mile x yr)	Cubic (gms/mile x yr)
II	HC	1,495	1,262	1,430
	CO	19,870	20,172	20,184
	NO_x	1,536	1,517	1,516
II-Pass	HC	1,325	1,330	1,334
	CO	19,891	20,142	18,366
	NO_x	1,545	1,512	1,512
II-Fail	HC	1,690	1,532	1,516
	CO	20,637	20,132	20,076
	NO_x	1,527	1,524	1,527
III	HC	1,398	1,379	1,376
	CO	18,657	18,528	18,554
	NO_x	1,463	1,473	1,477
IV	HC	1,537	1,514	1,507
	CO	19,083	19,097	19,067
	NO_x	1,341	1,463	1,364

Table 4-6. REFERENCE GROUP DATA

GROUP	POLLUTANT	AS-RECEIVED EMISSIONS GM/MILE	% DEGRADATION (1 YEAR)	GMS/MILE X YR	COST OF MAINT. $
Reference (for II,III, & IV)	HC	4.21	28.9	1,759	$32.36
"	CO	60.03	10.8	23,092	32.36
"	NO_x	3.91	-8.2	1,369	32.36
Reference (II Fail)	HC	6.2	28.9	2,591	30.14
"	CO	71.8	10.8	27,704	30.14
"	NO_x	4.11	-8.2	1,438	30.14

Table 4-7. Group Maintenance Cost Effectiveness
(Average Vehicles)

Group No.	Pollutant	Δ gms/mile x yr	Δ gms	Δ Pounds	Δ Cost $	$/#
II	HC	264	8,679	19.0	18.05	0.95
	CO	3,222	105,929	232	18.05	0.08
	NO_x	-167	-5,490	-12.0	18.05	--
II Fail	HC	901	29,622	65	30.14	0.46
	CO	7,067	232,340	510	30.14	0.06
	NO_x	-89	-2,926	-6.4	30.14	--
III	HC	361	11,868	26.0	84.18	3.24
	CO	4,435	145,808	320	84.18	0.26
	NO_x	-94	-3,090	-6.8	84.18	--
IV	HC	222	7,299	16.0	63.09	3.94
	CO	4,009	131,803	289	63.09	0.22
	NO_x	28	920	2.0	63.09	--

considered. As exhibited by Group III, when manufacturer's maintenance is followed, the lowest emission over time and mileage is attained.

Cost-effectiveness was examined over a 1-year period for each of the maintenance regimes. It is clear that the most cost-effective approach in achieving emission reductions of the cases examined is only to repair those vehicles which require service.

Finally, it appears that on the average emission after maintenance at the end of the 12-month period, closely approximated the previous baseline level attained.

Section 5

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A P P E N D I X   A

PLOTS OF EMISSION DEGRADATION AS A FUNCTION OF MODEL-YEAR AND GROUP

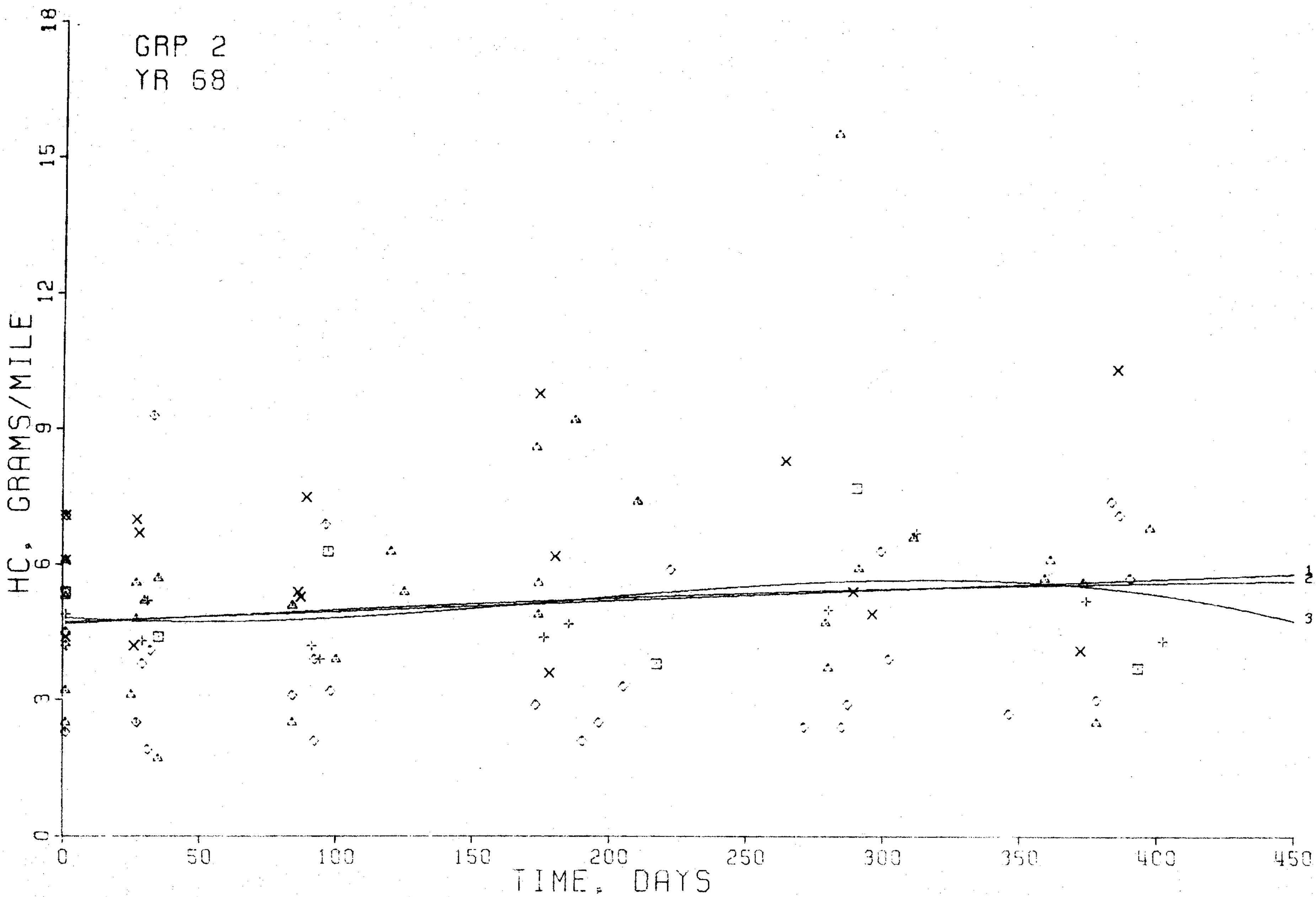
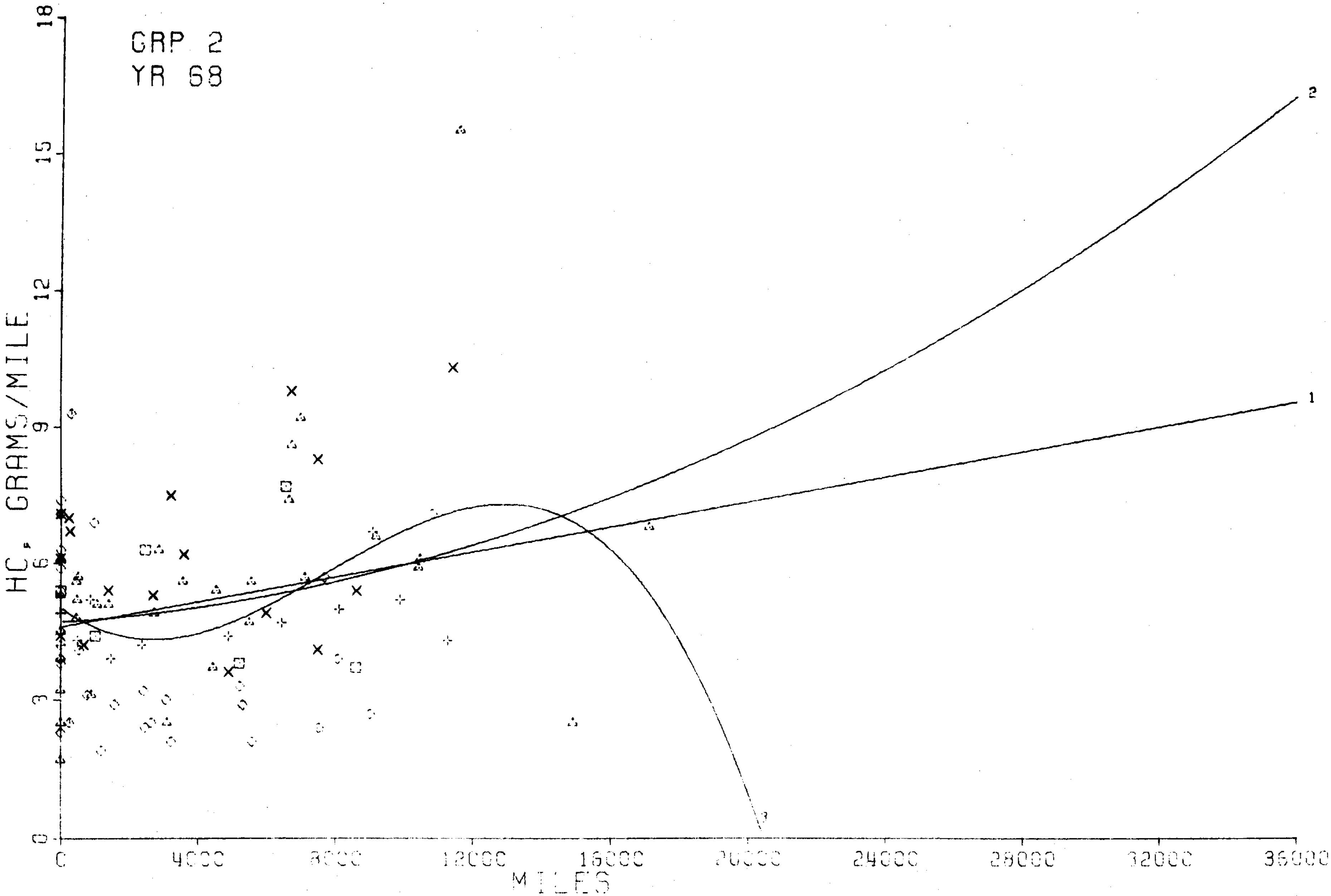


Figure A-1. DEGRADATION VS. TIME



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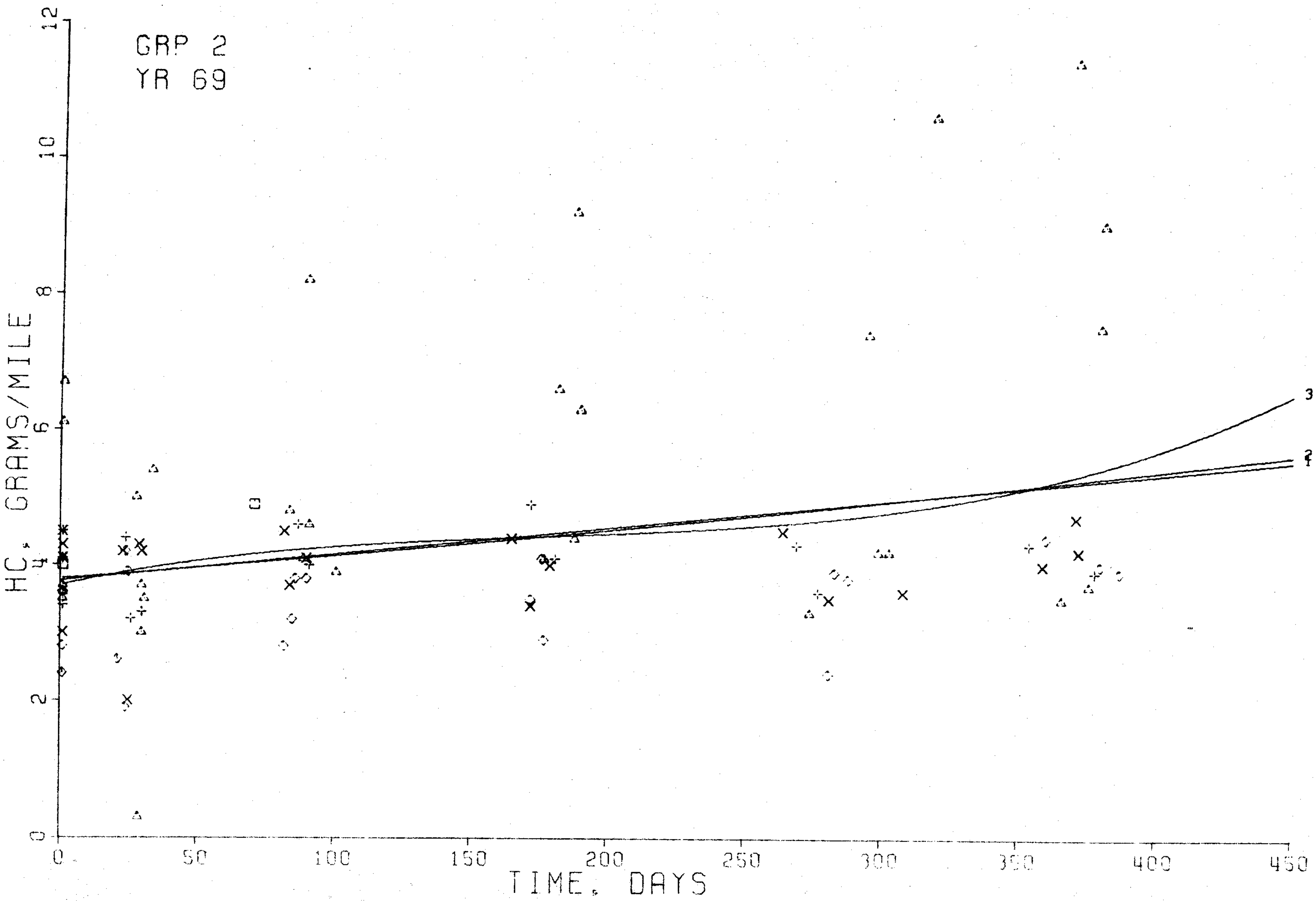

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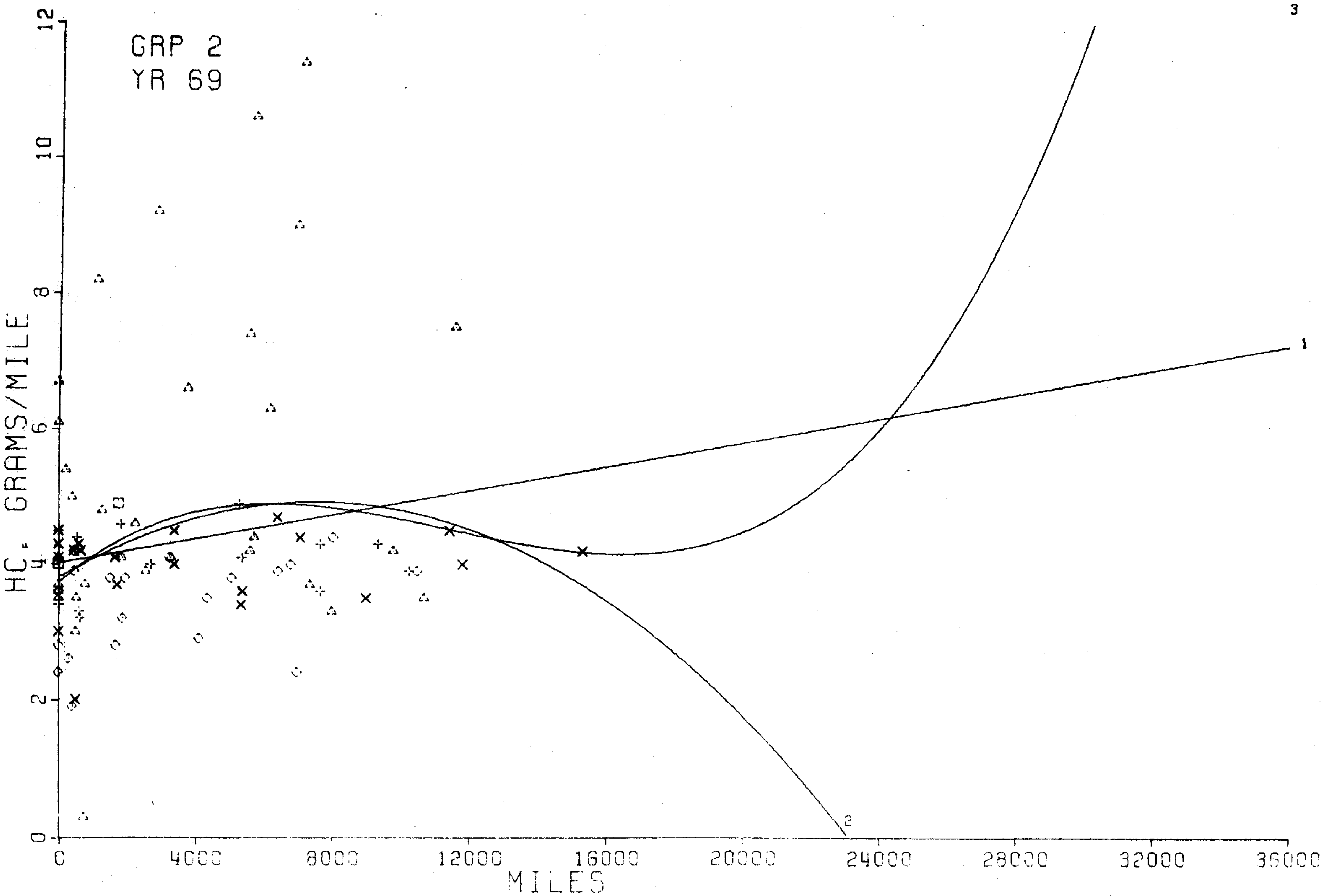

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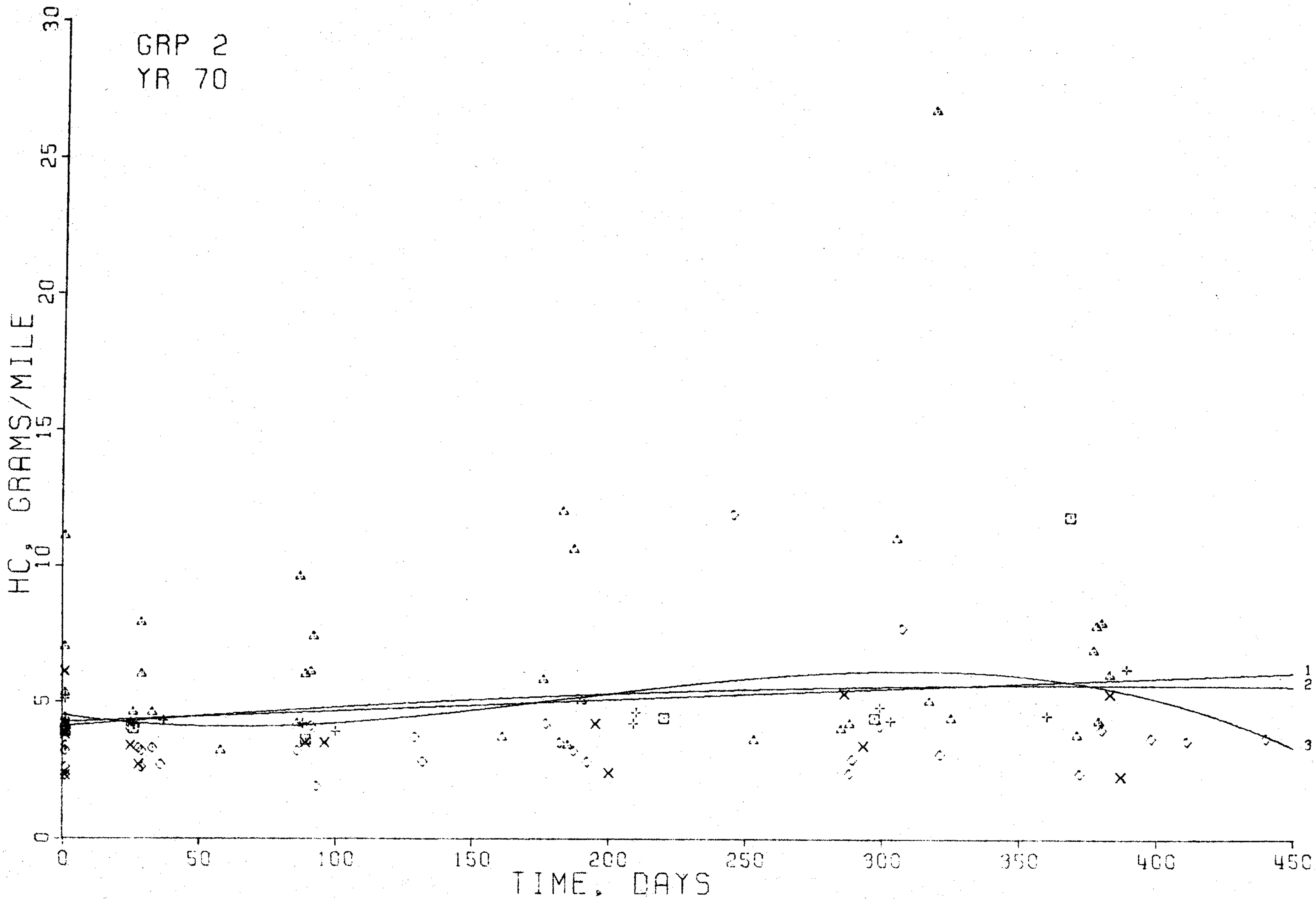

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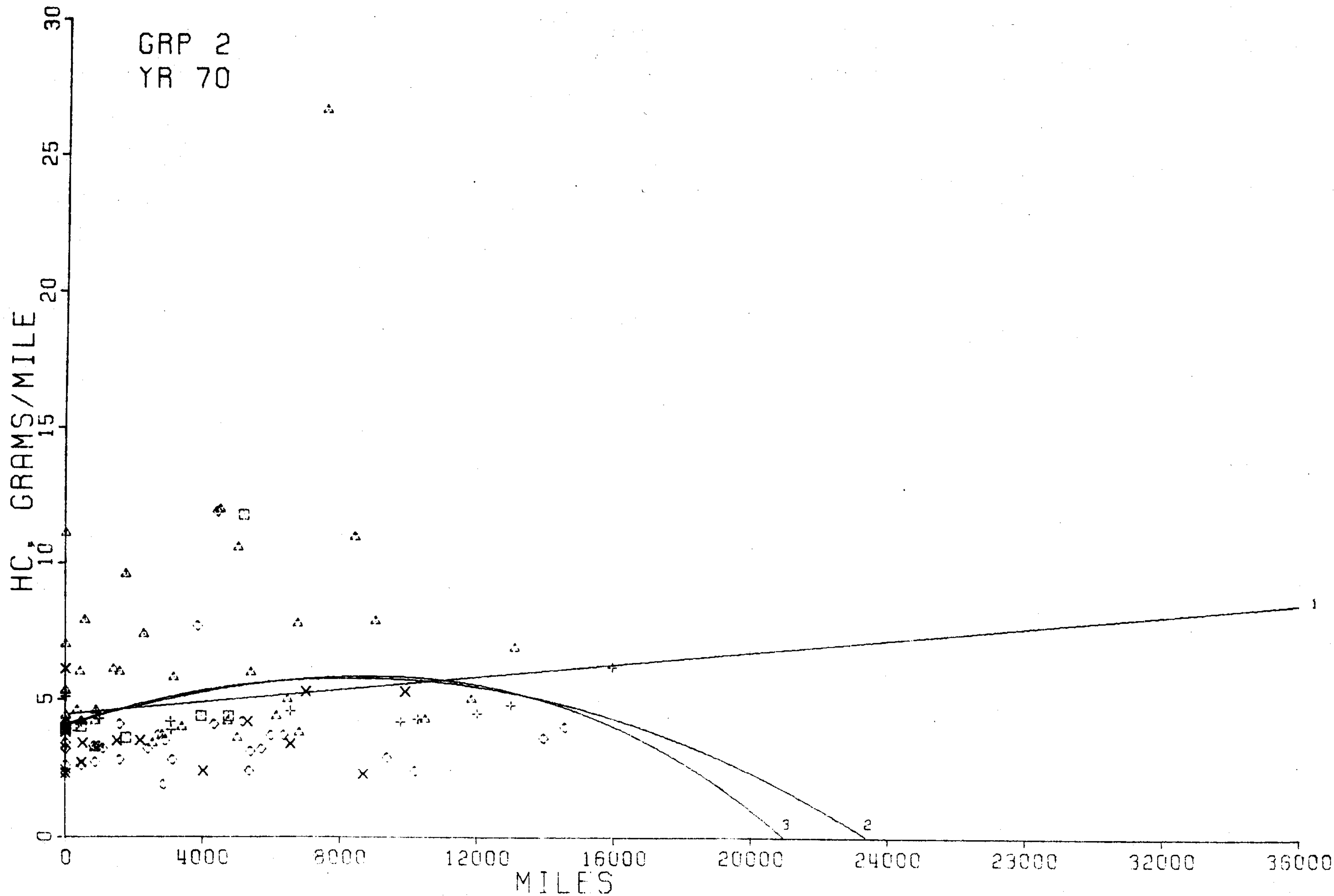

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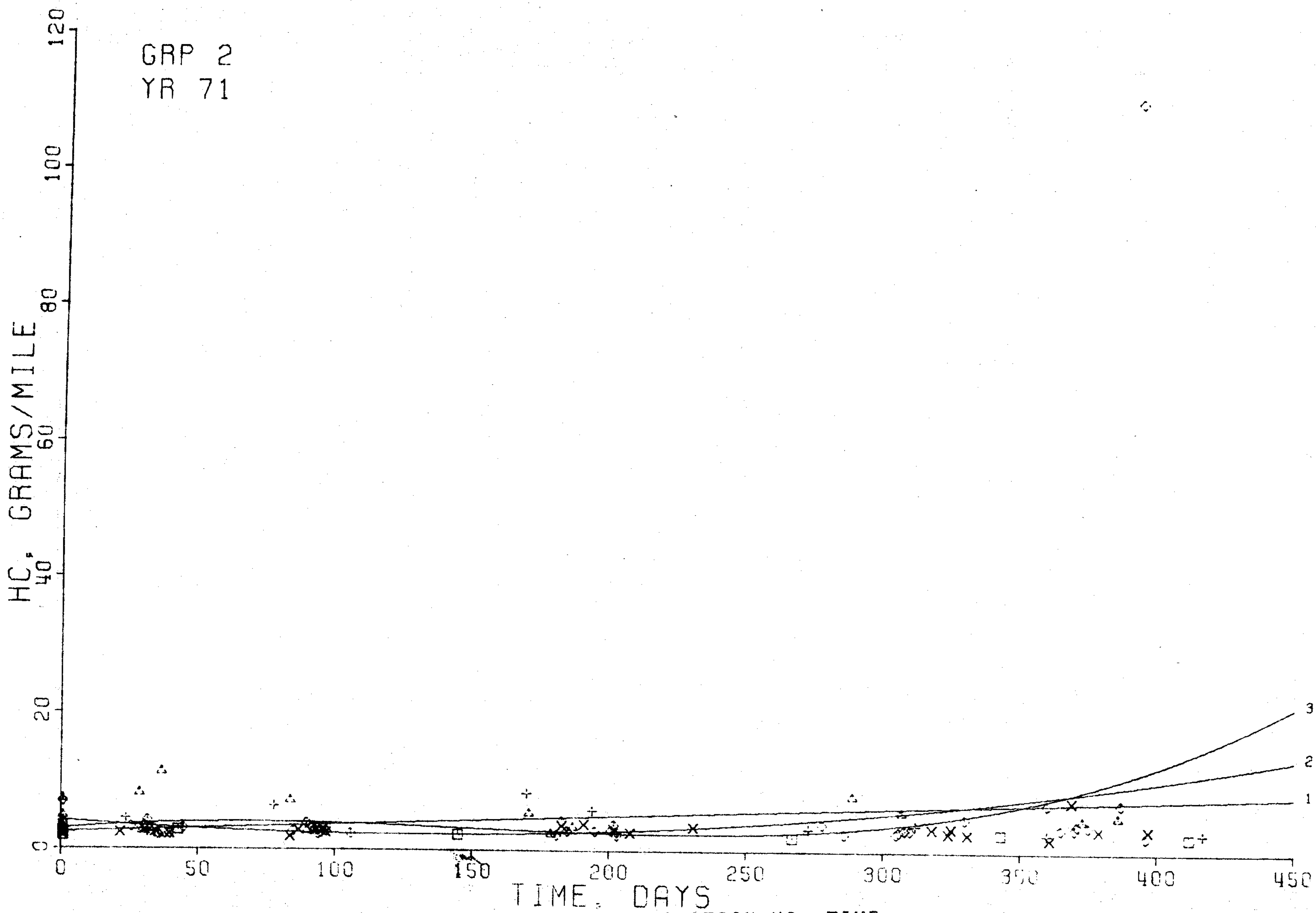

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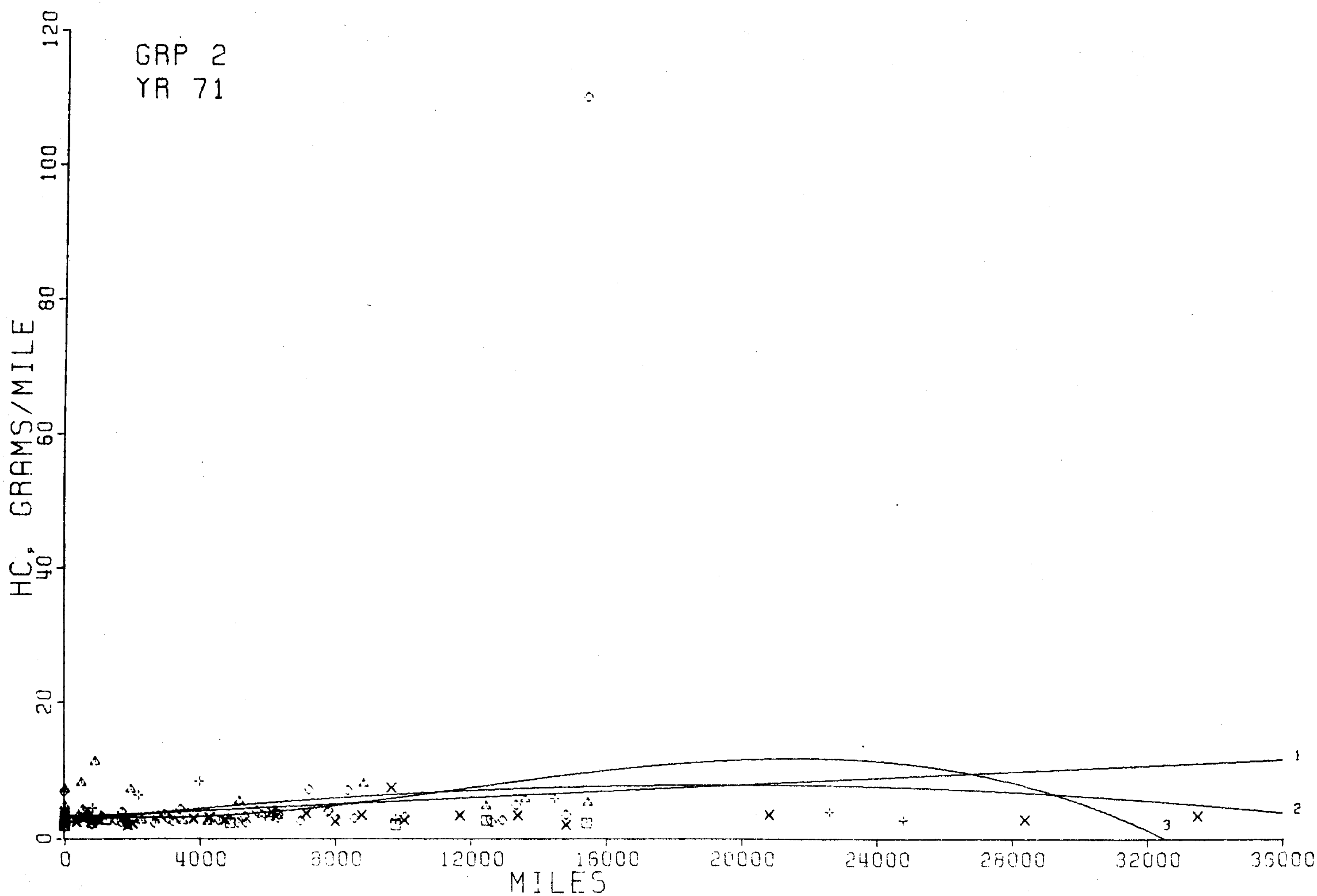

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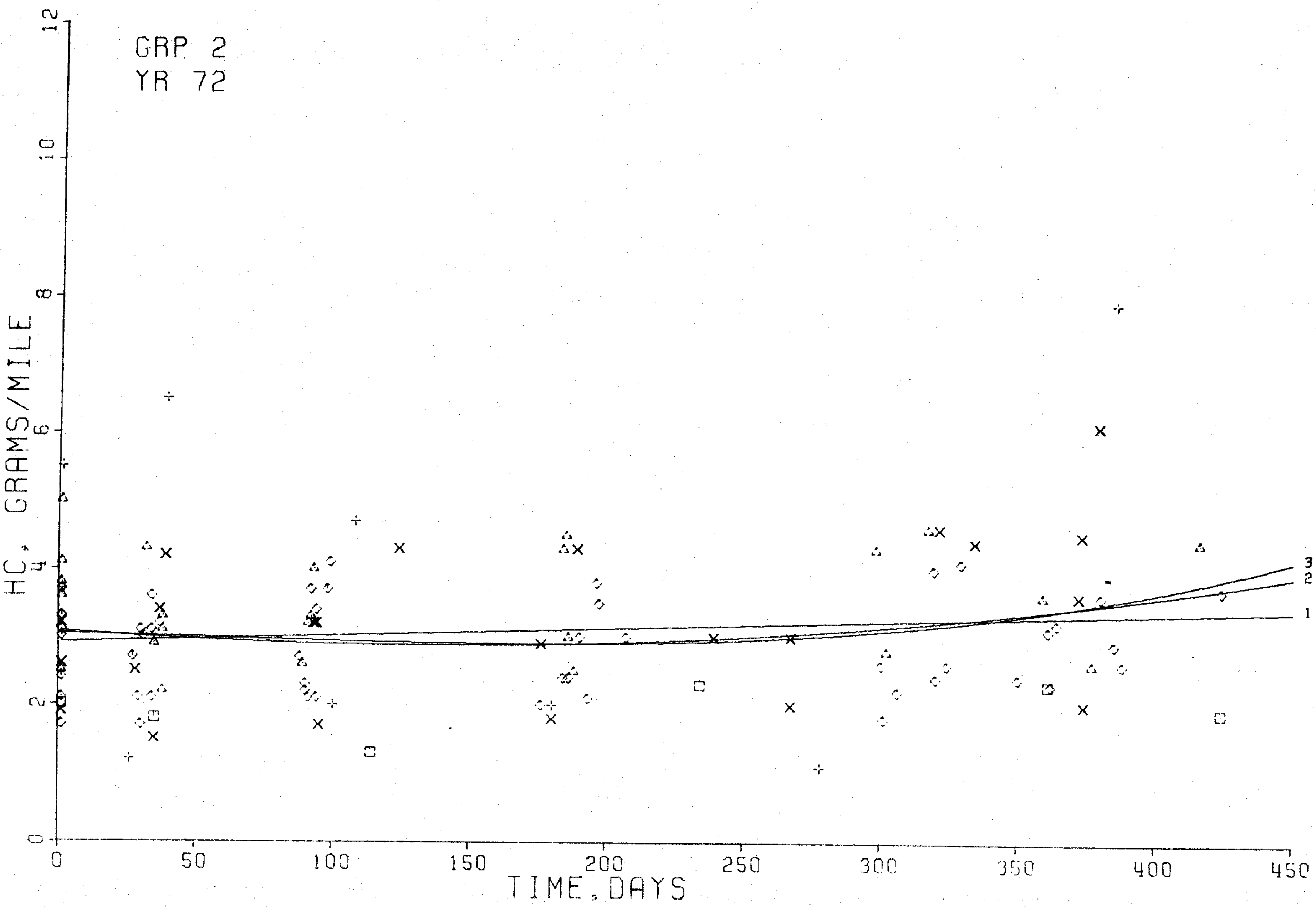

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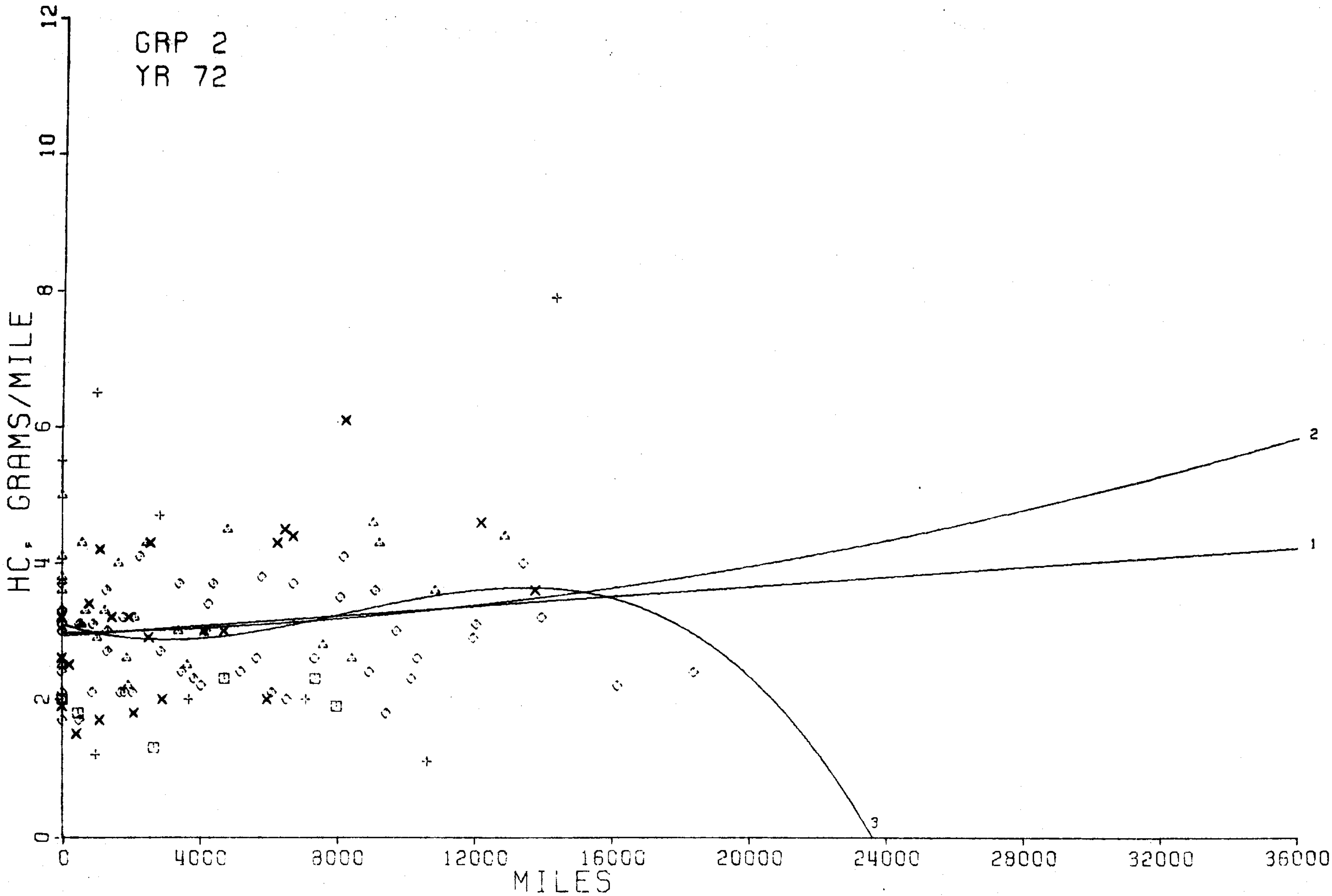

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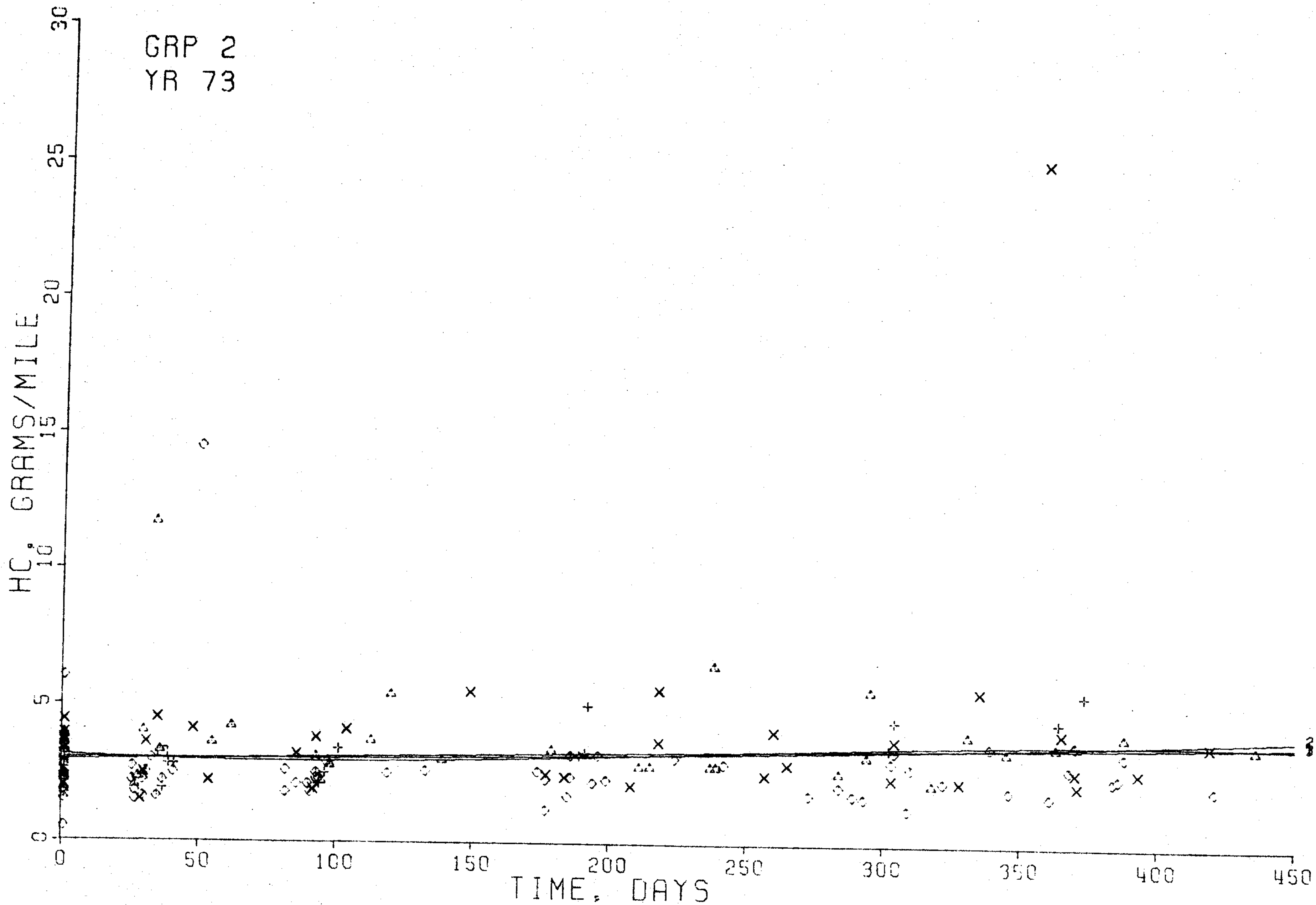

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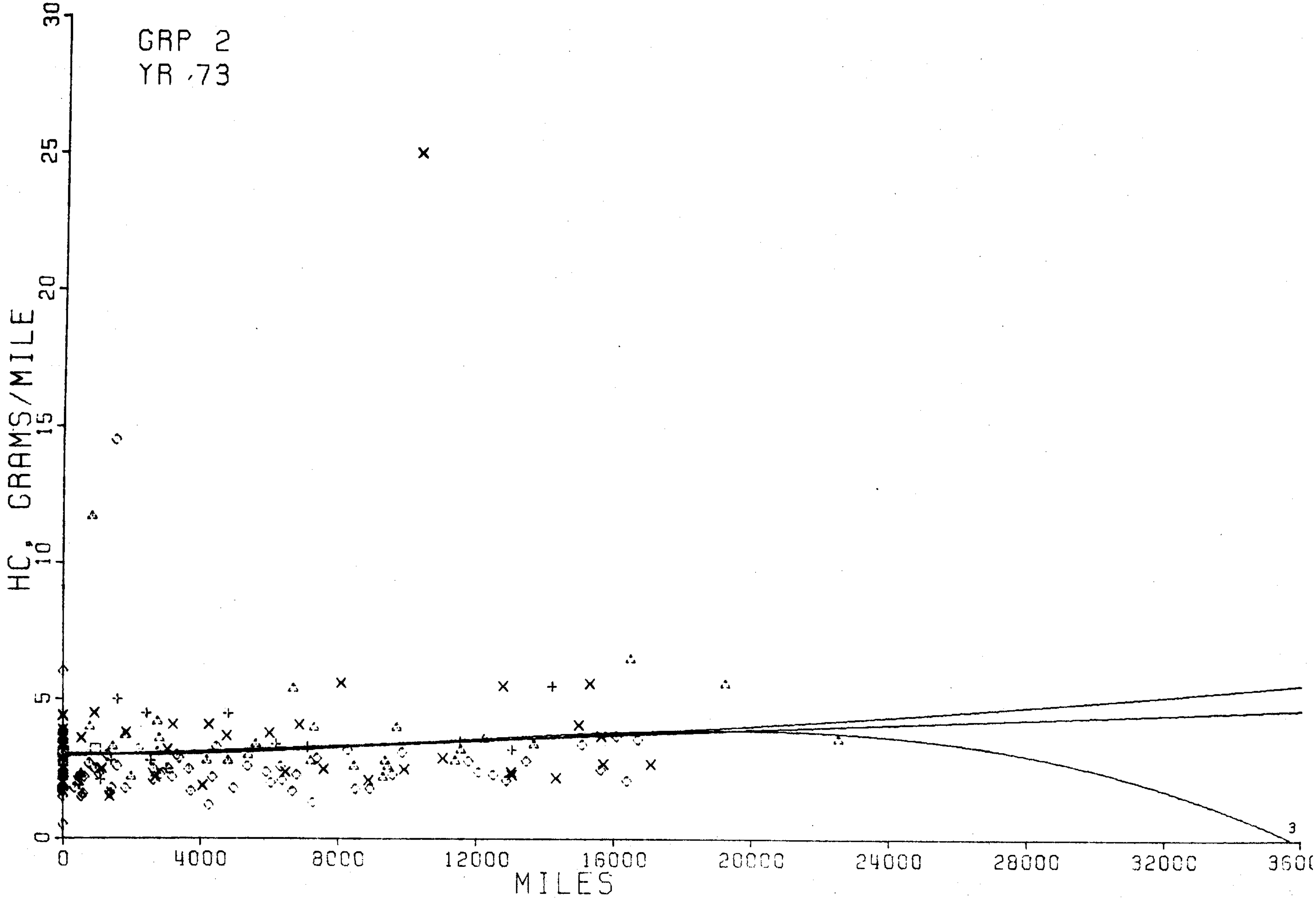

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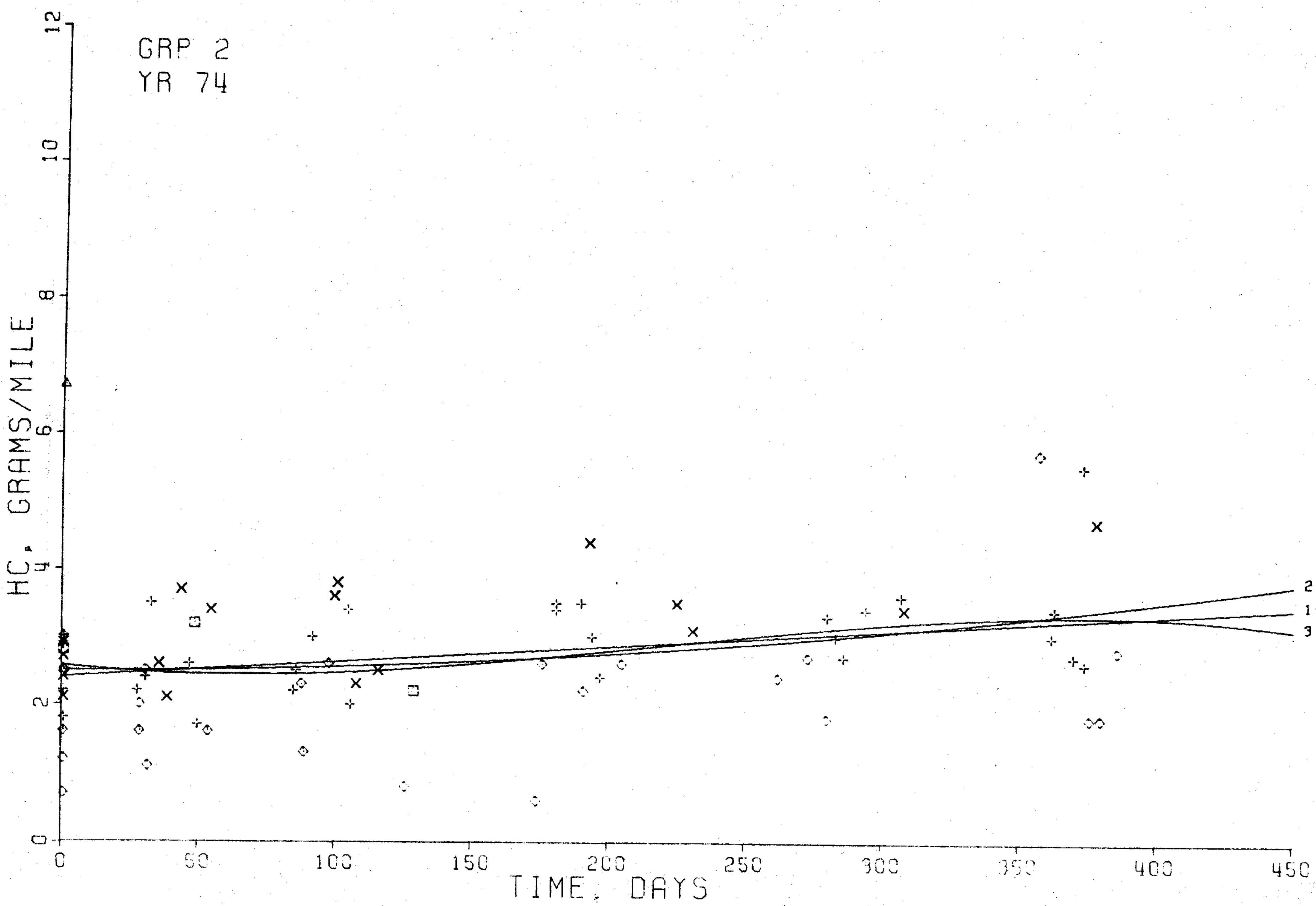

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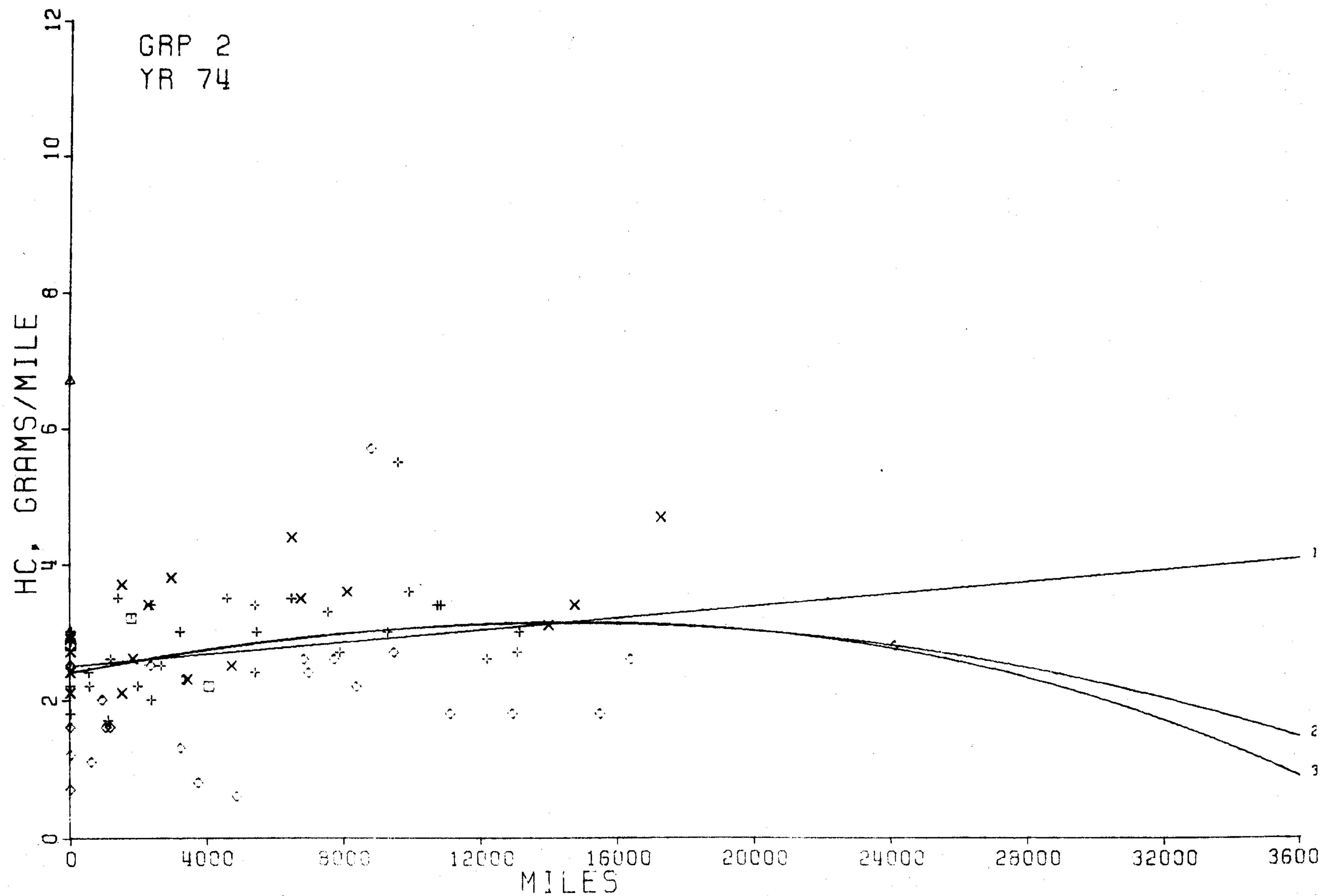

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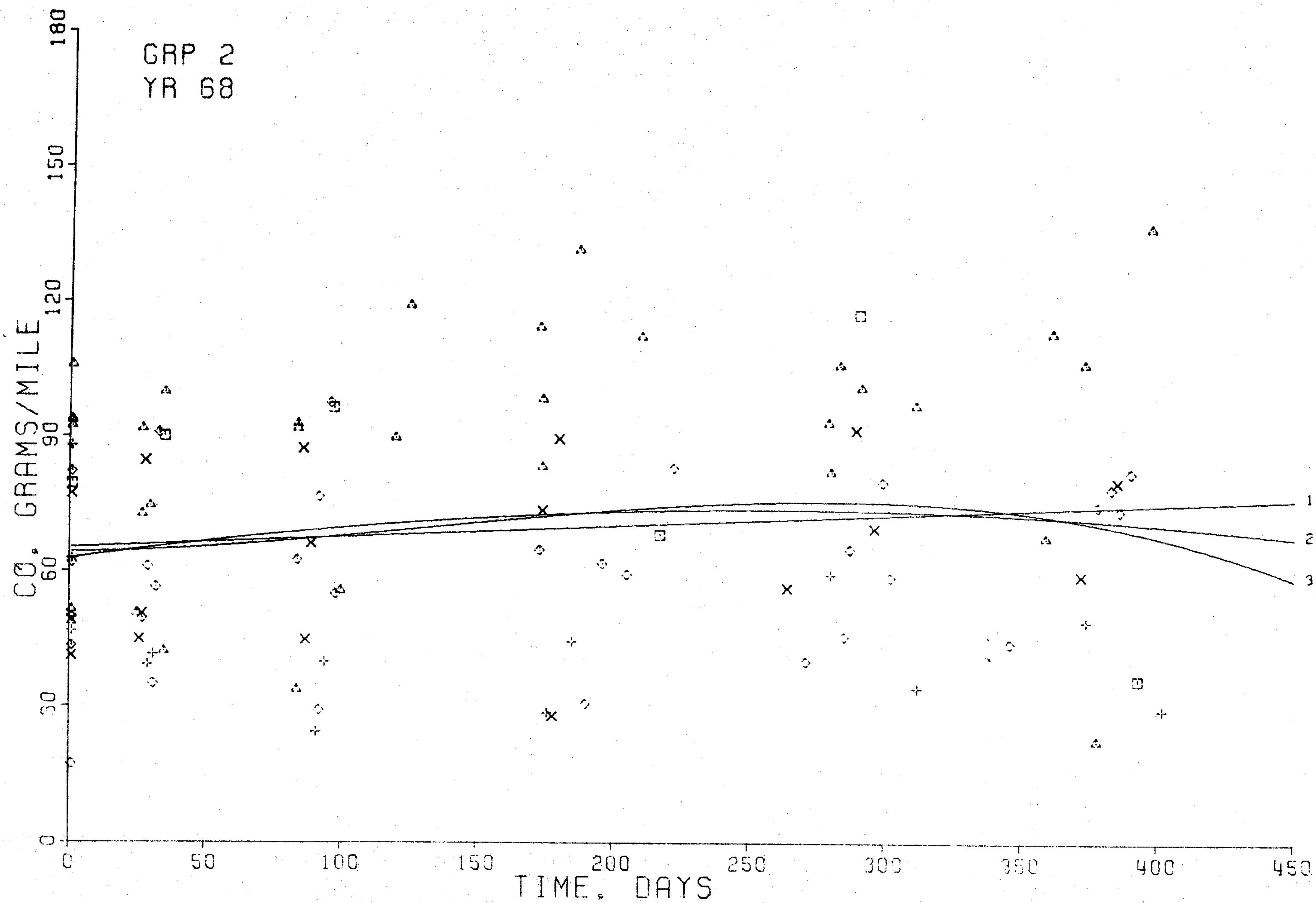

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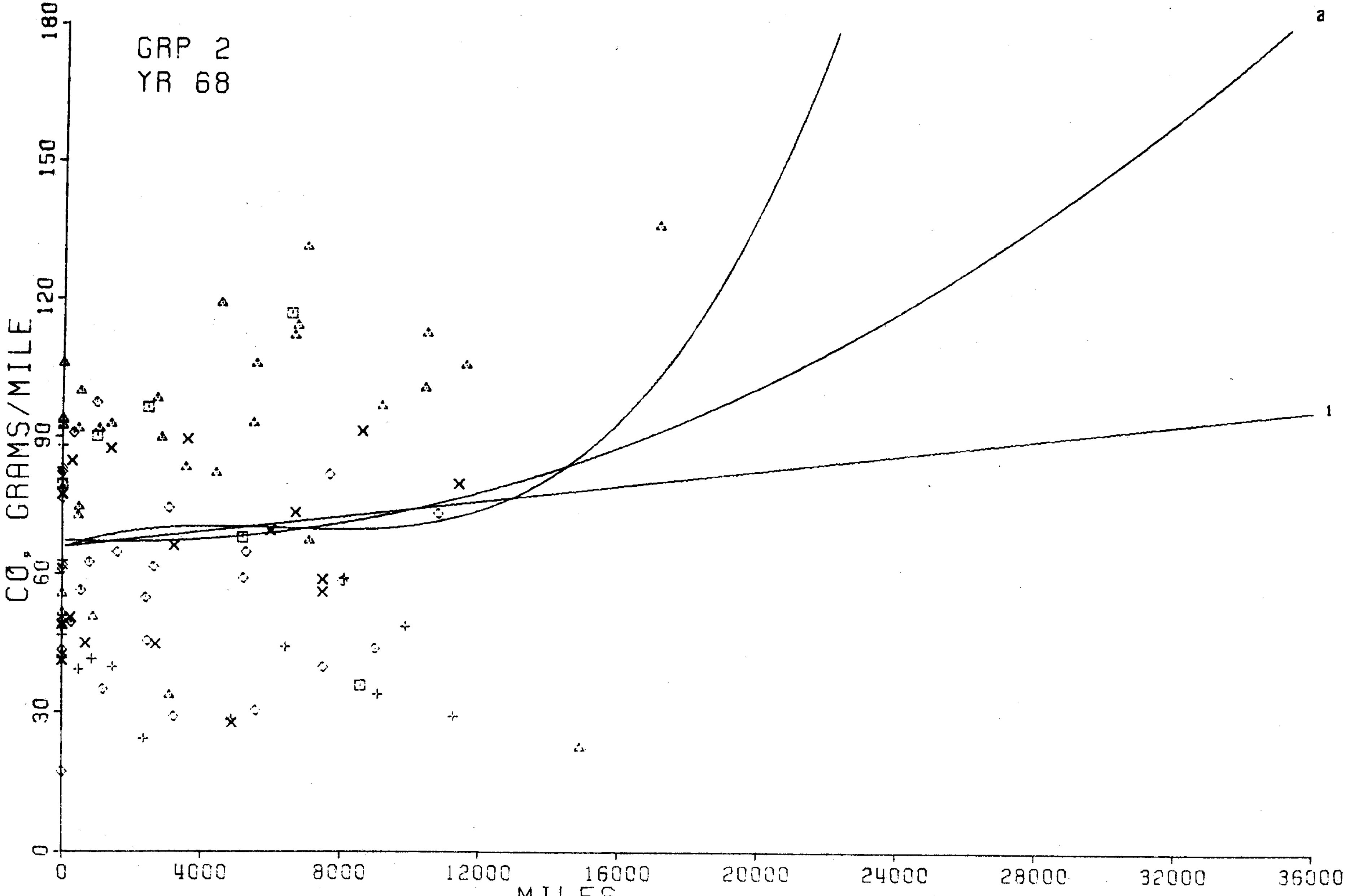

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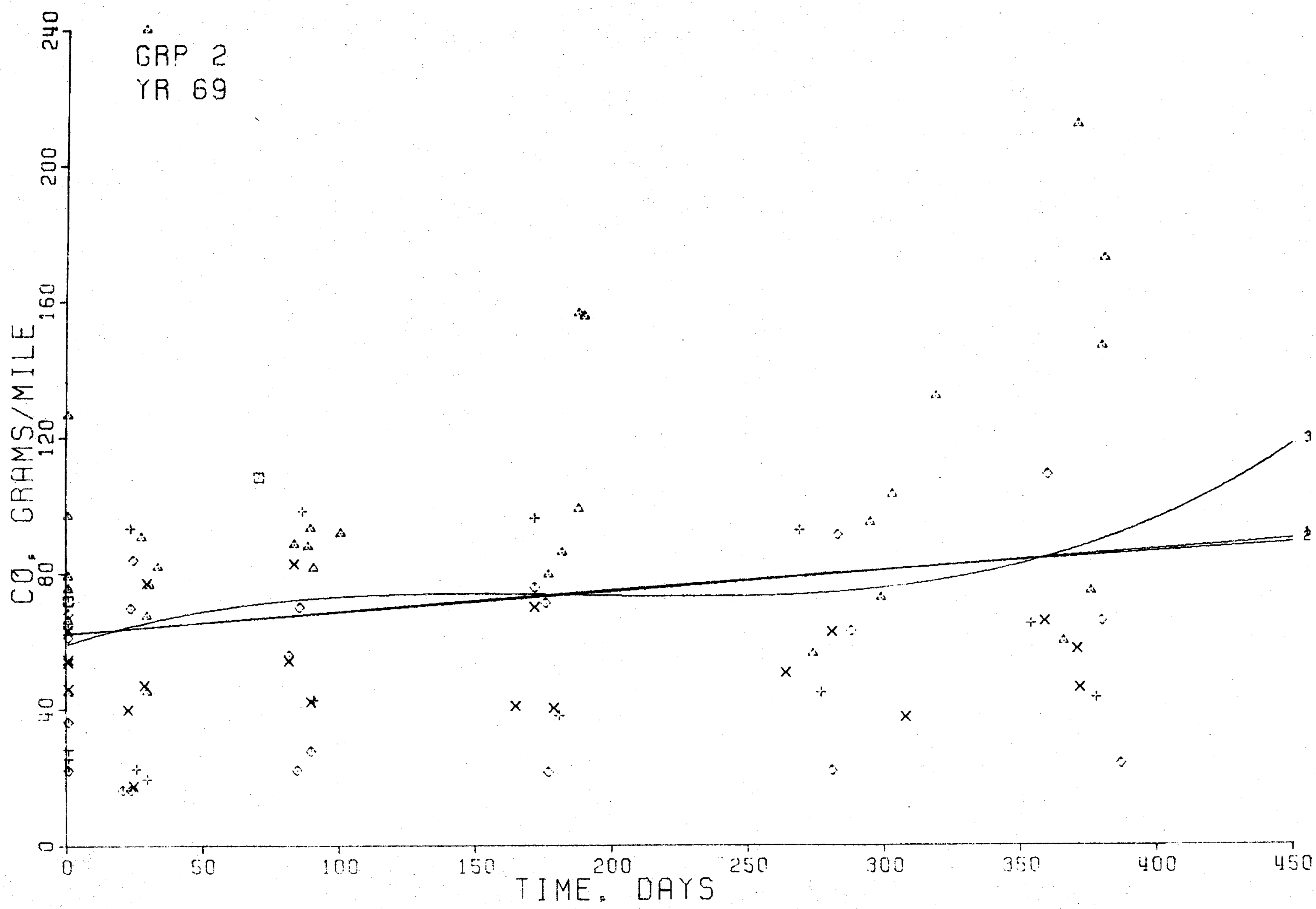

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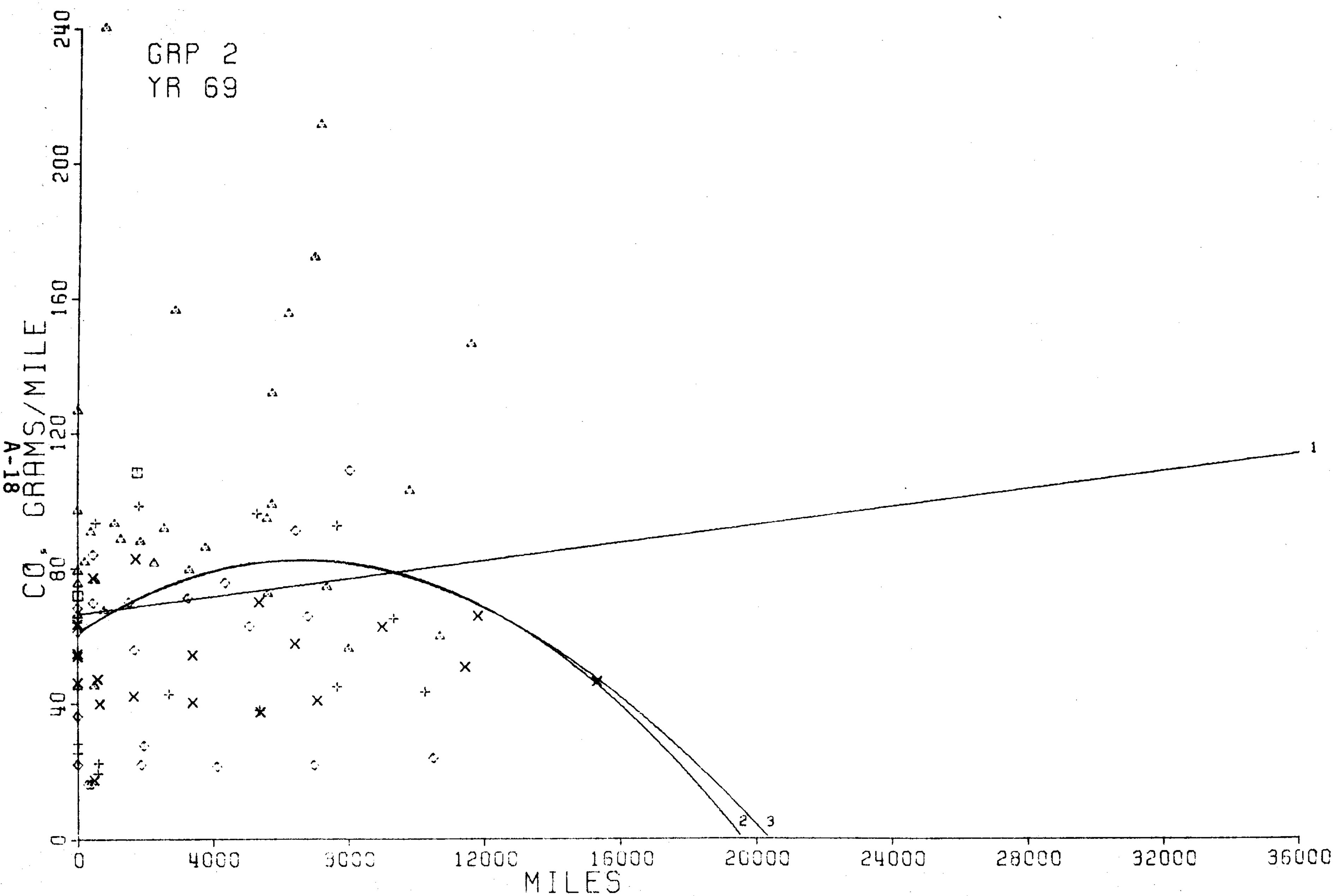

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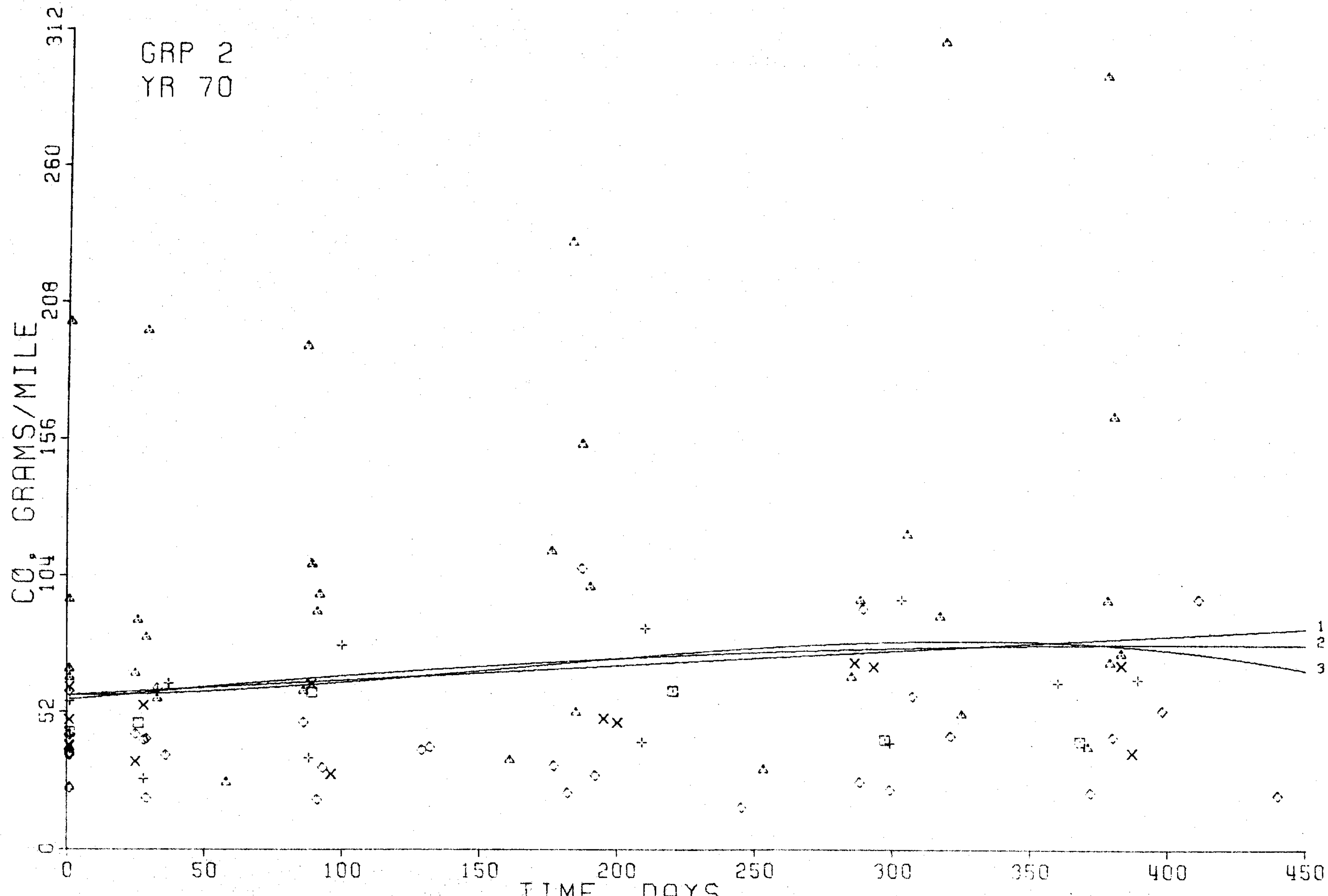

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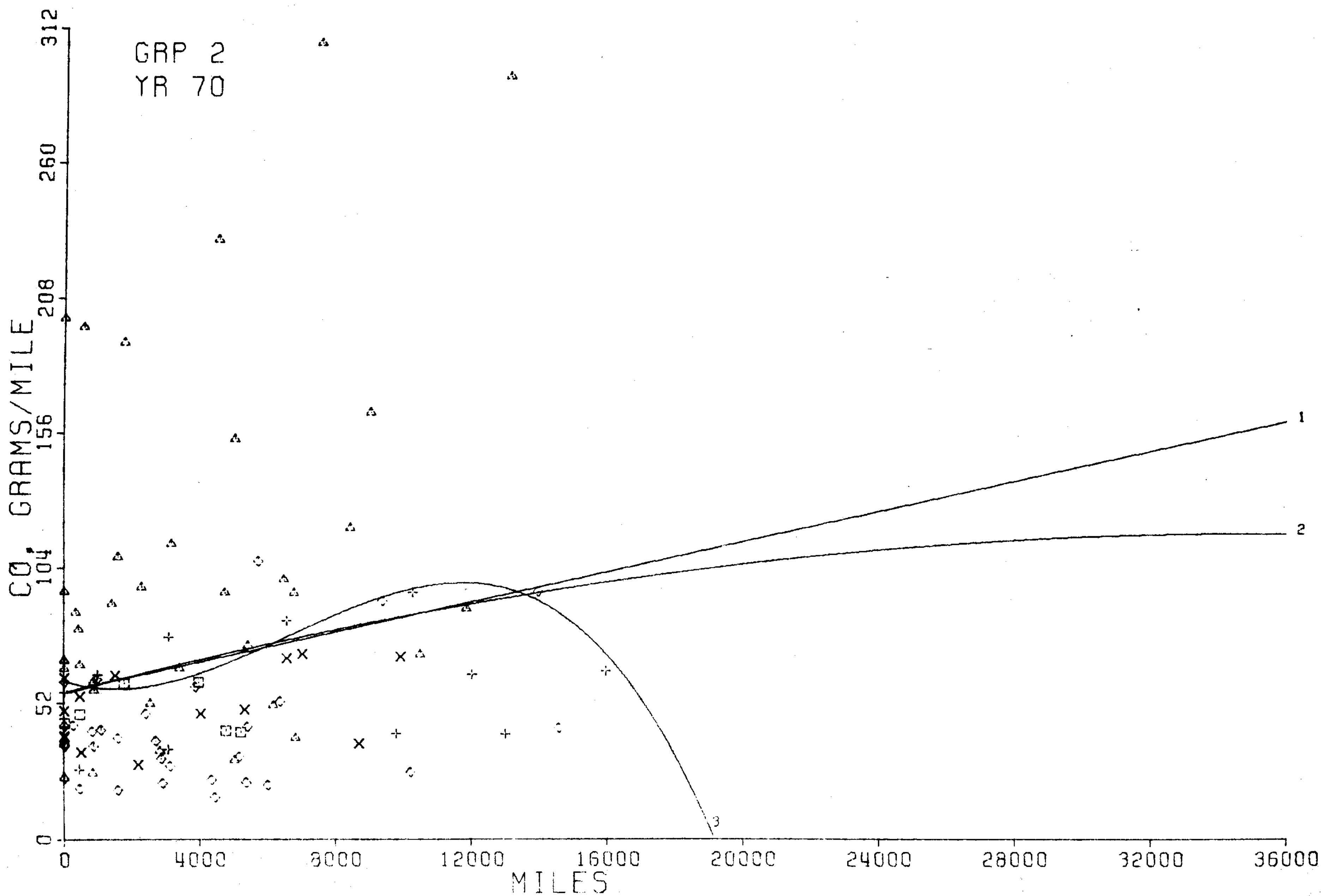

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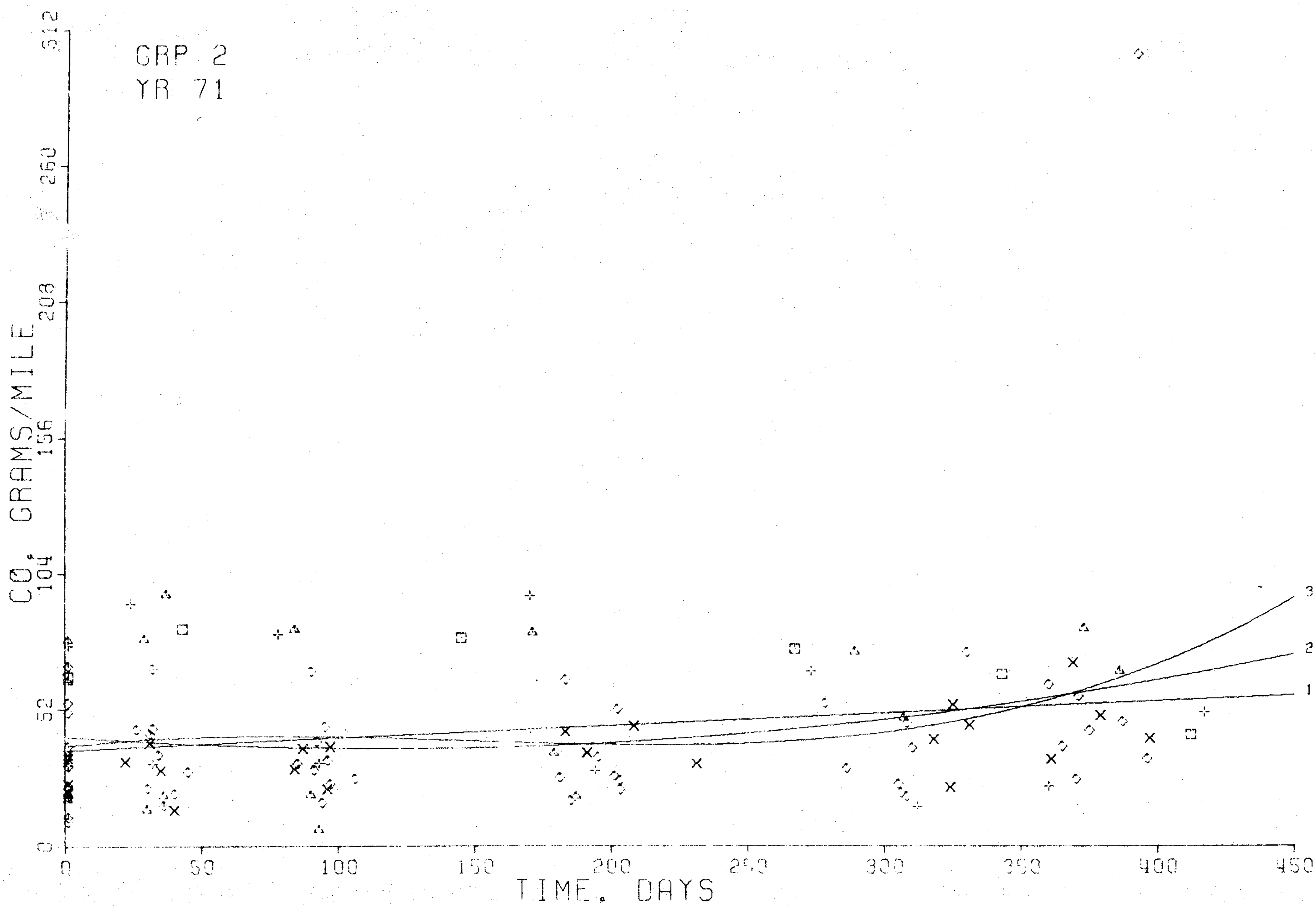

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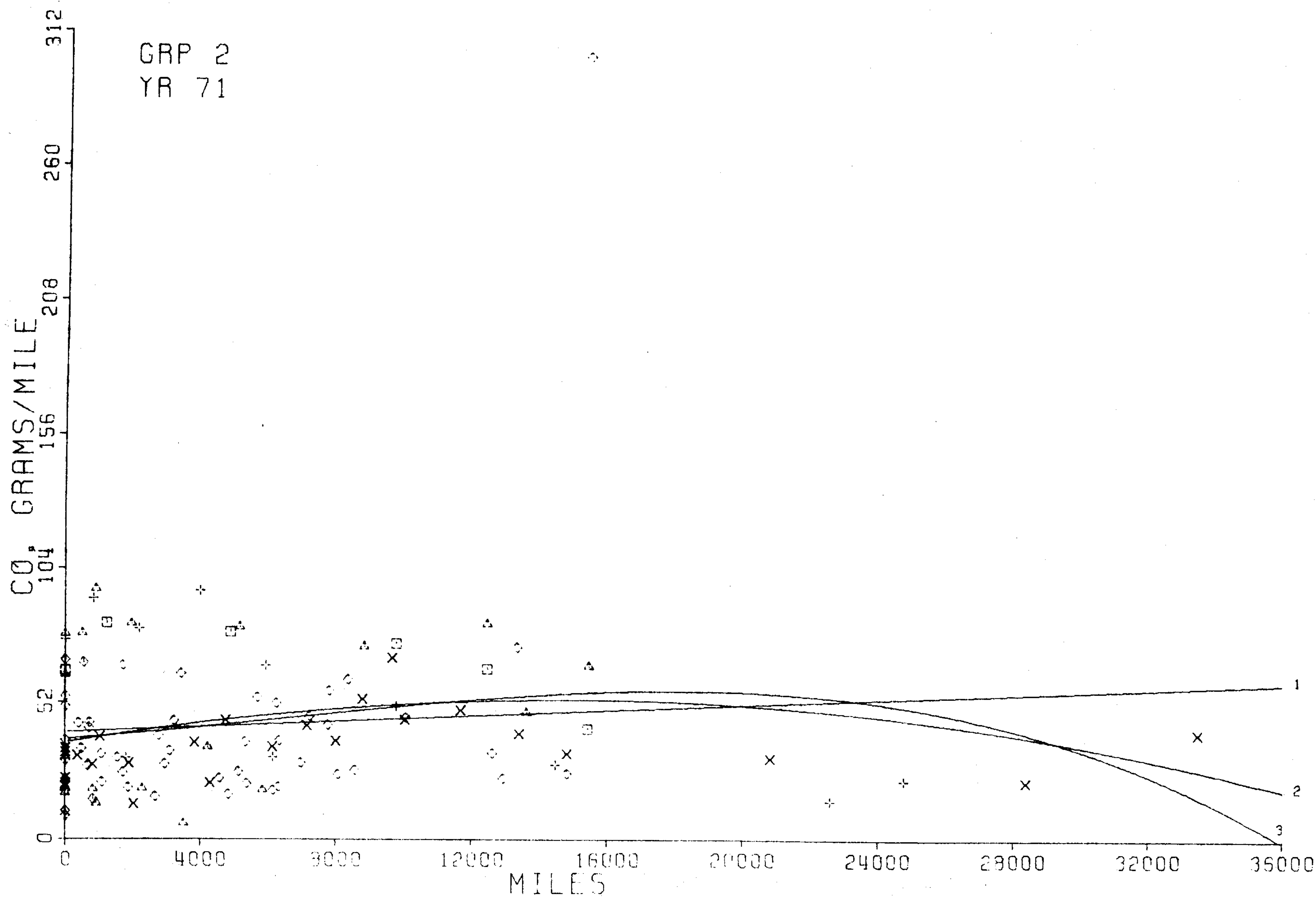

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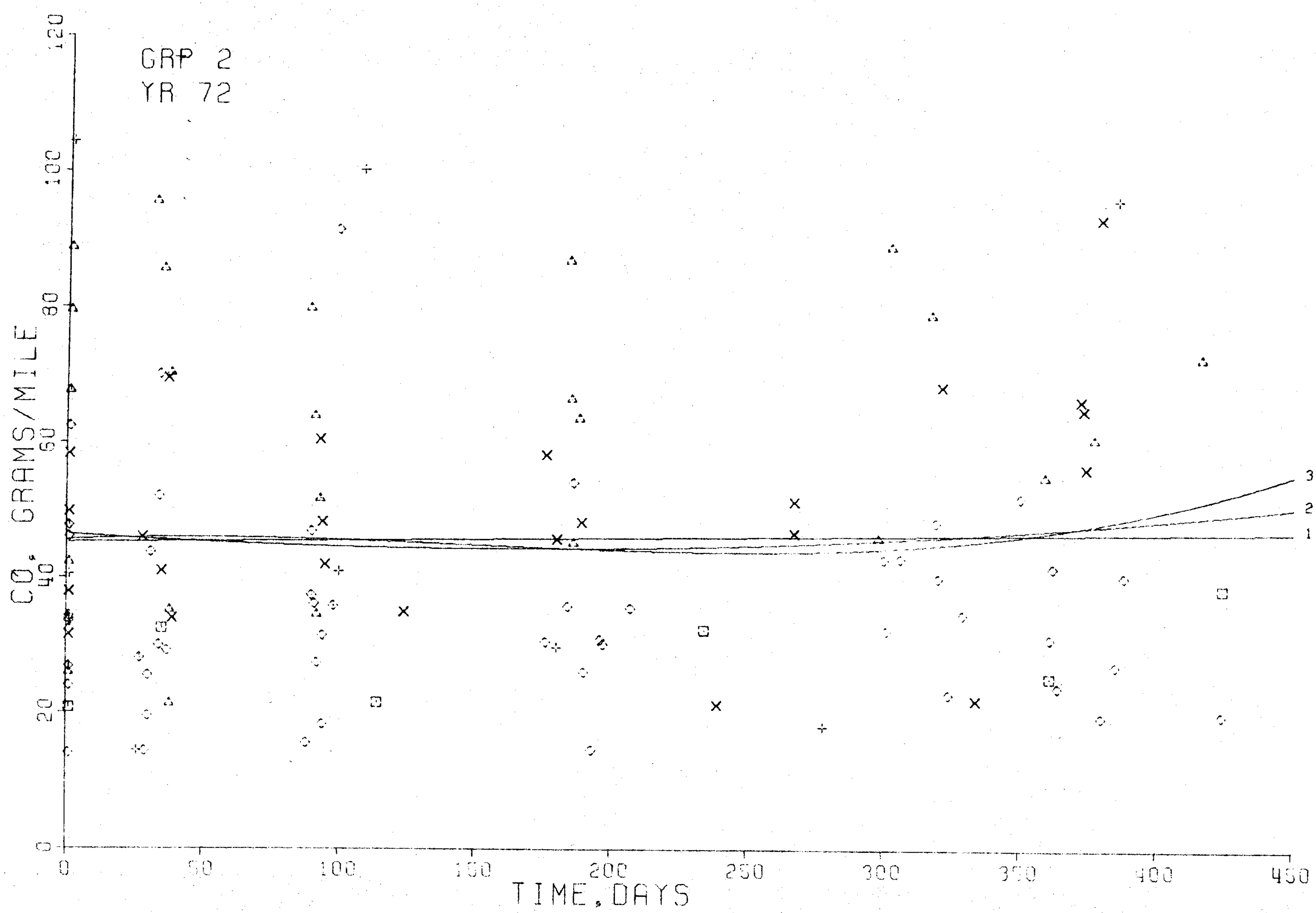

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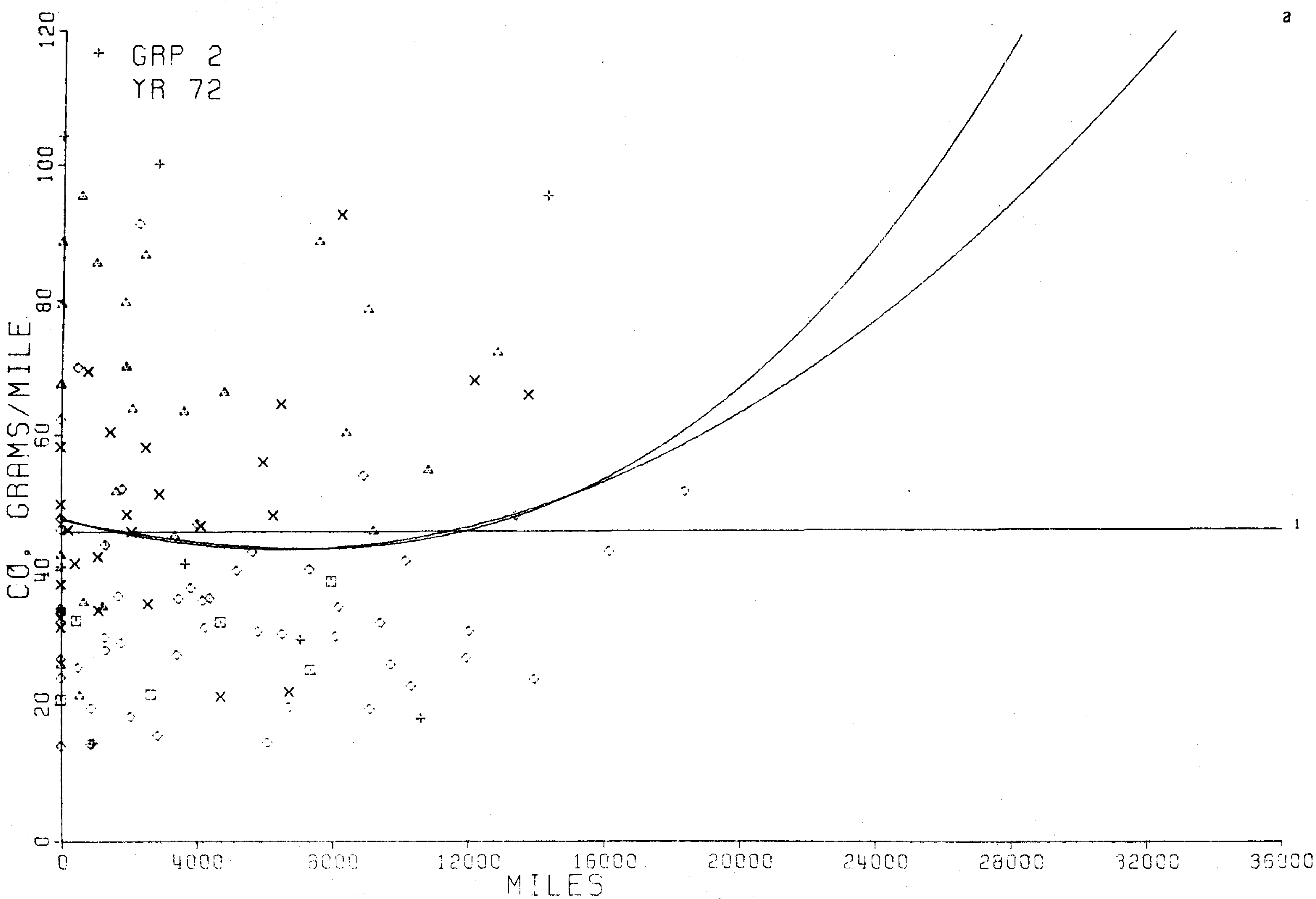

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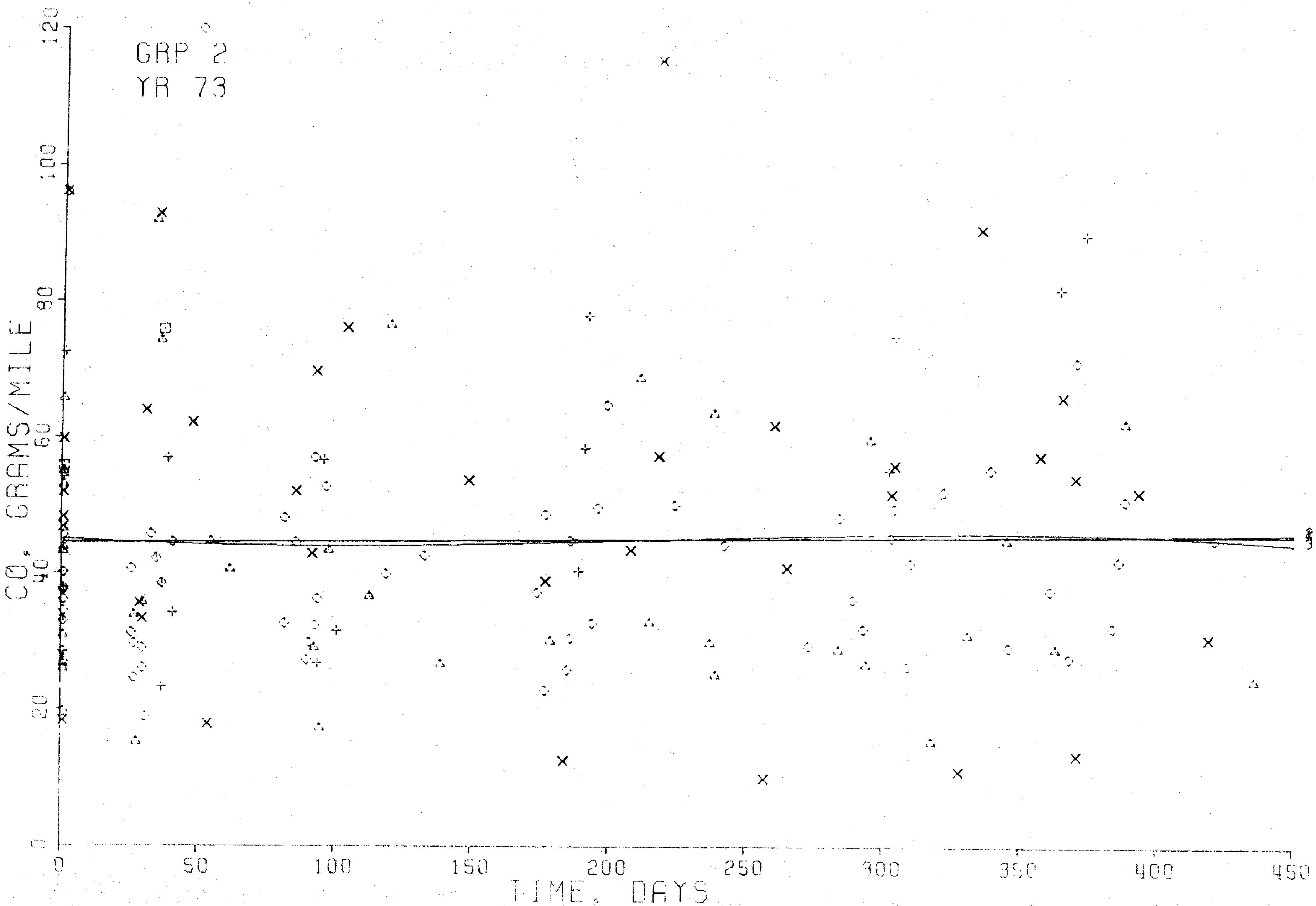

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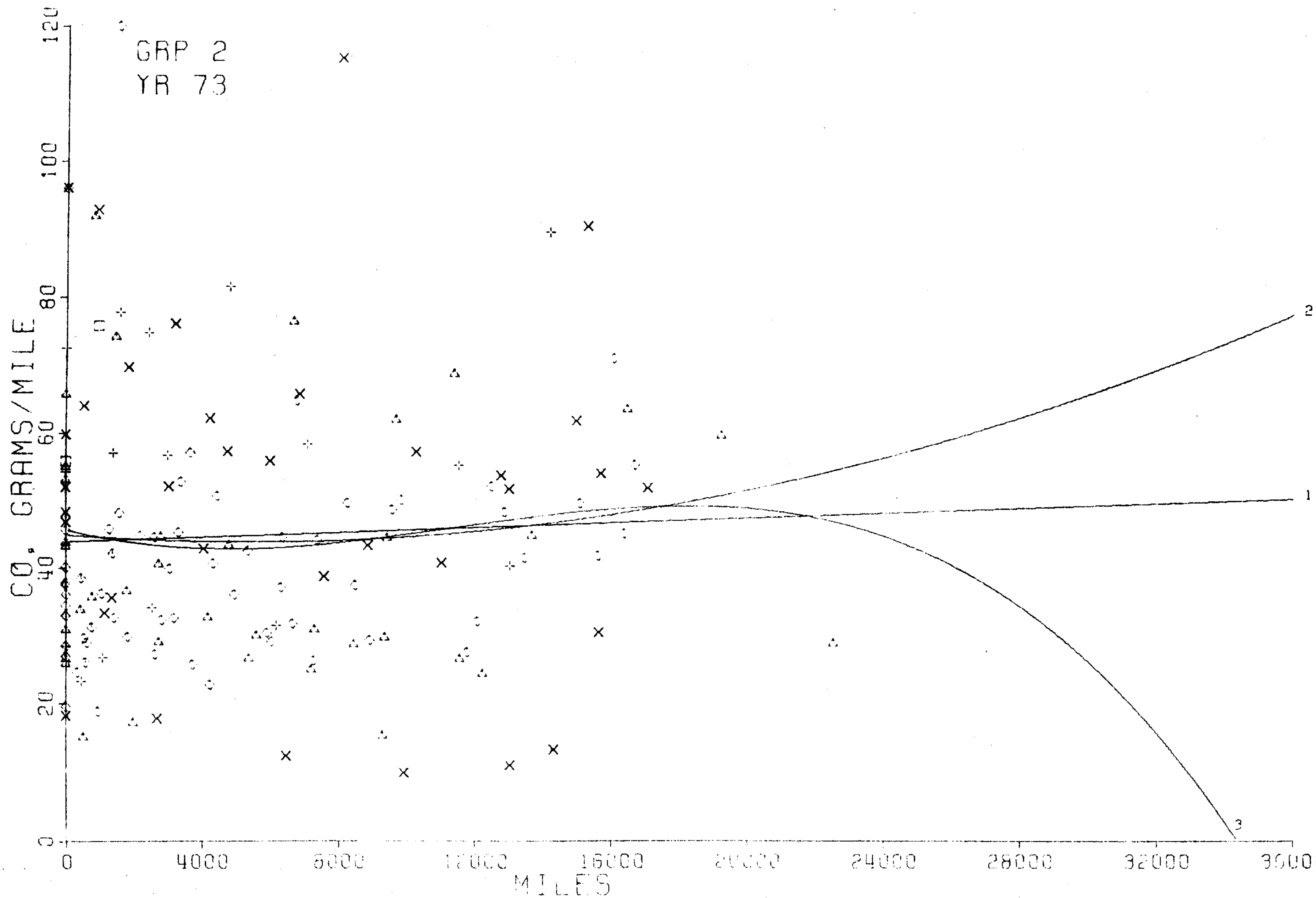

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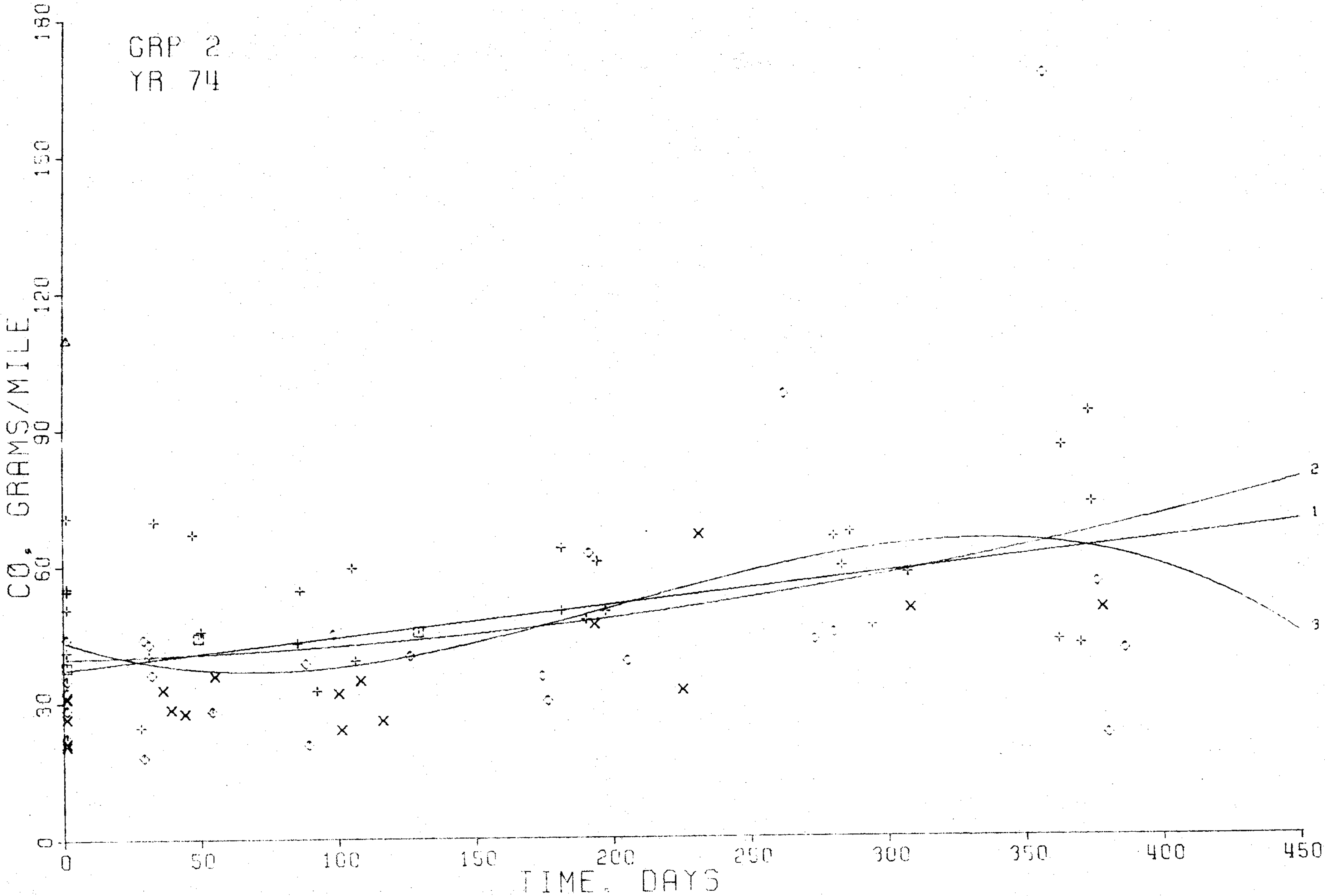

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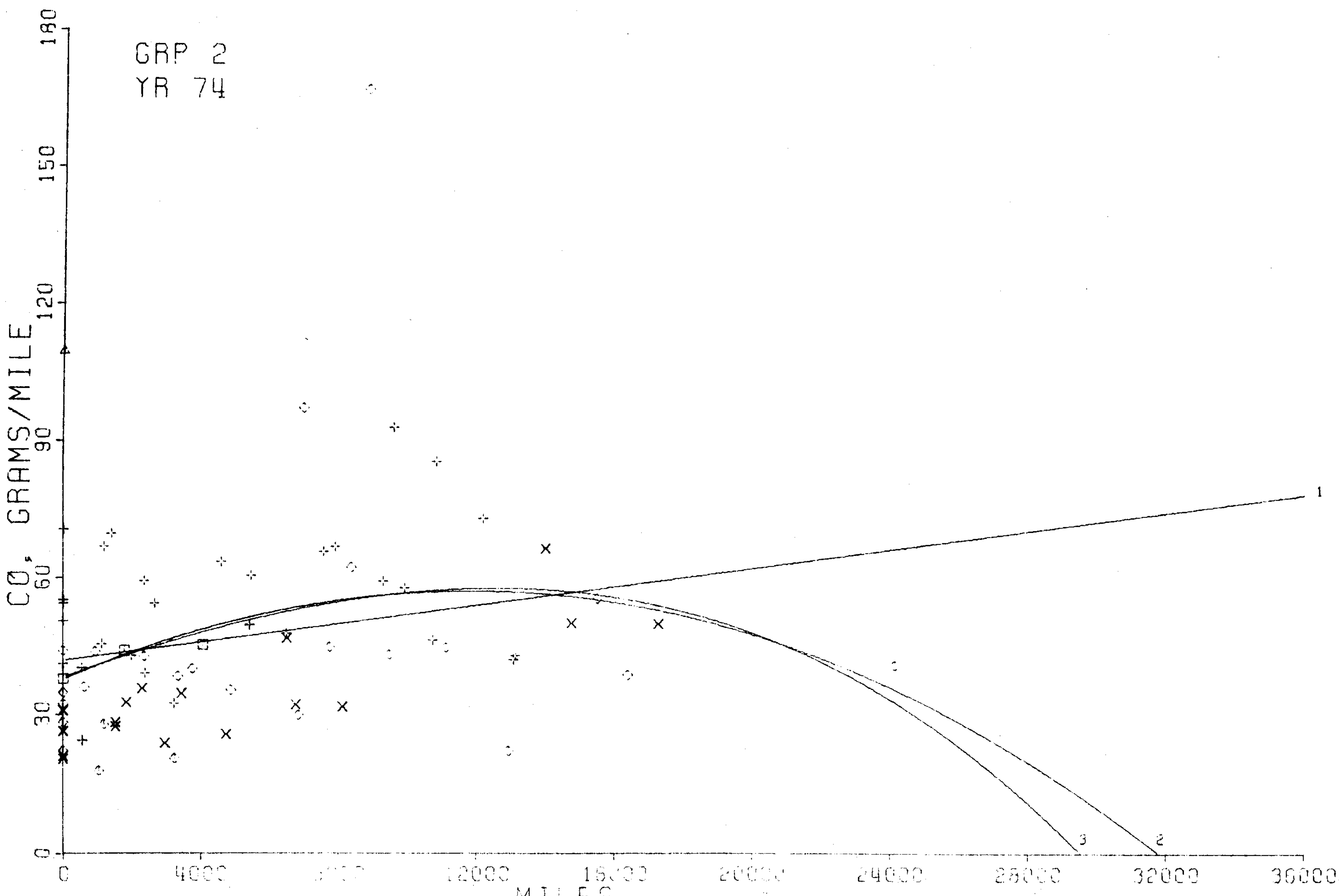

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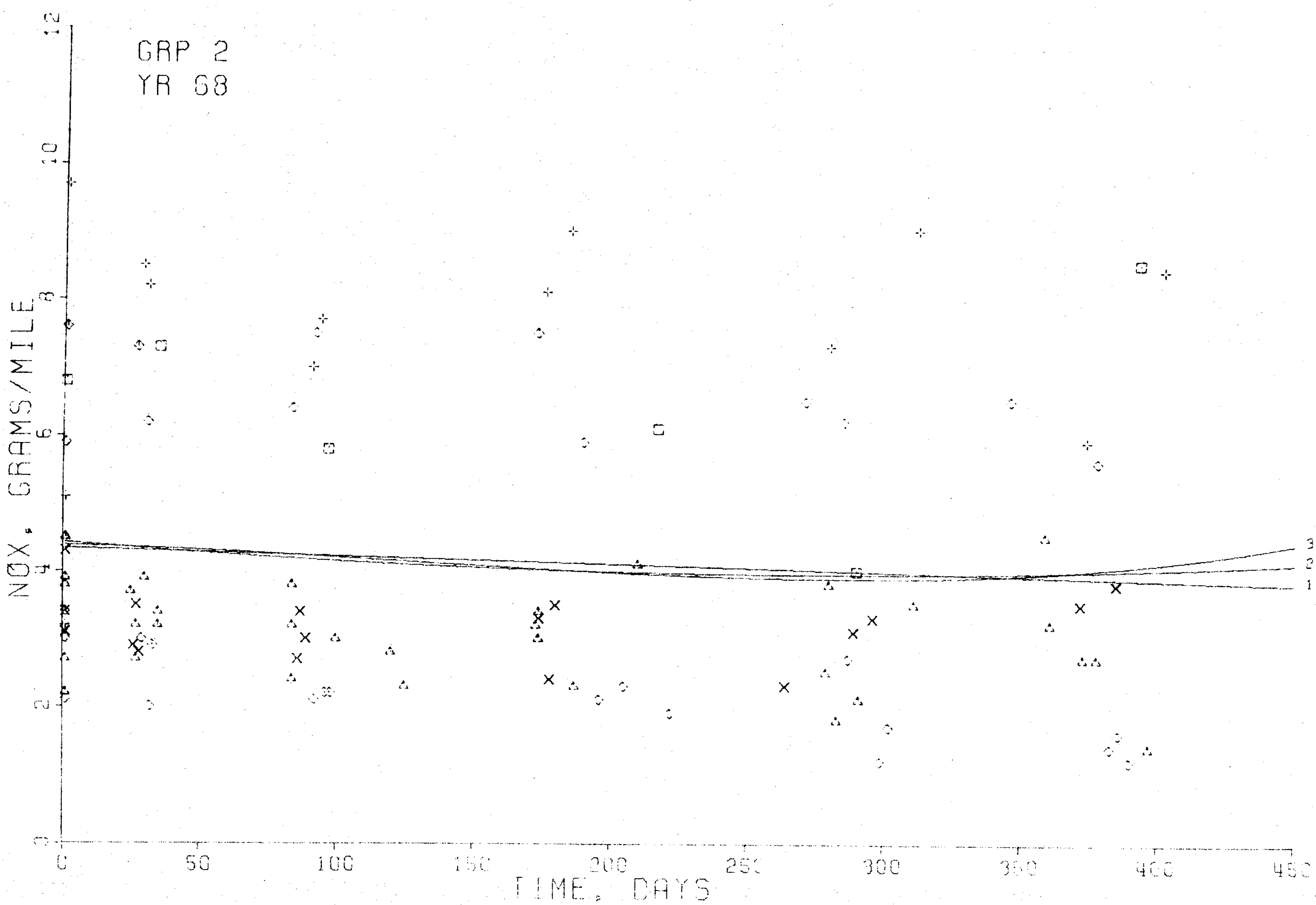

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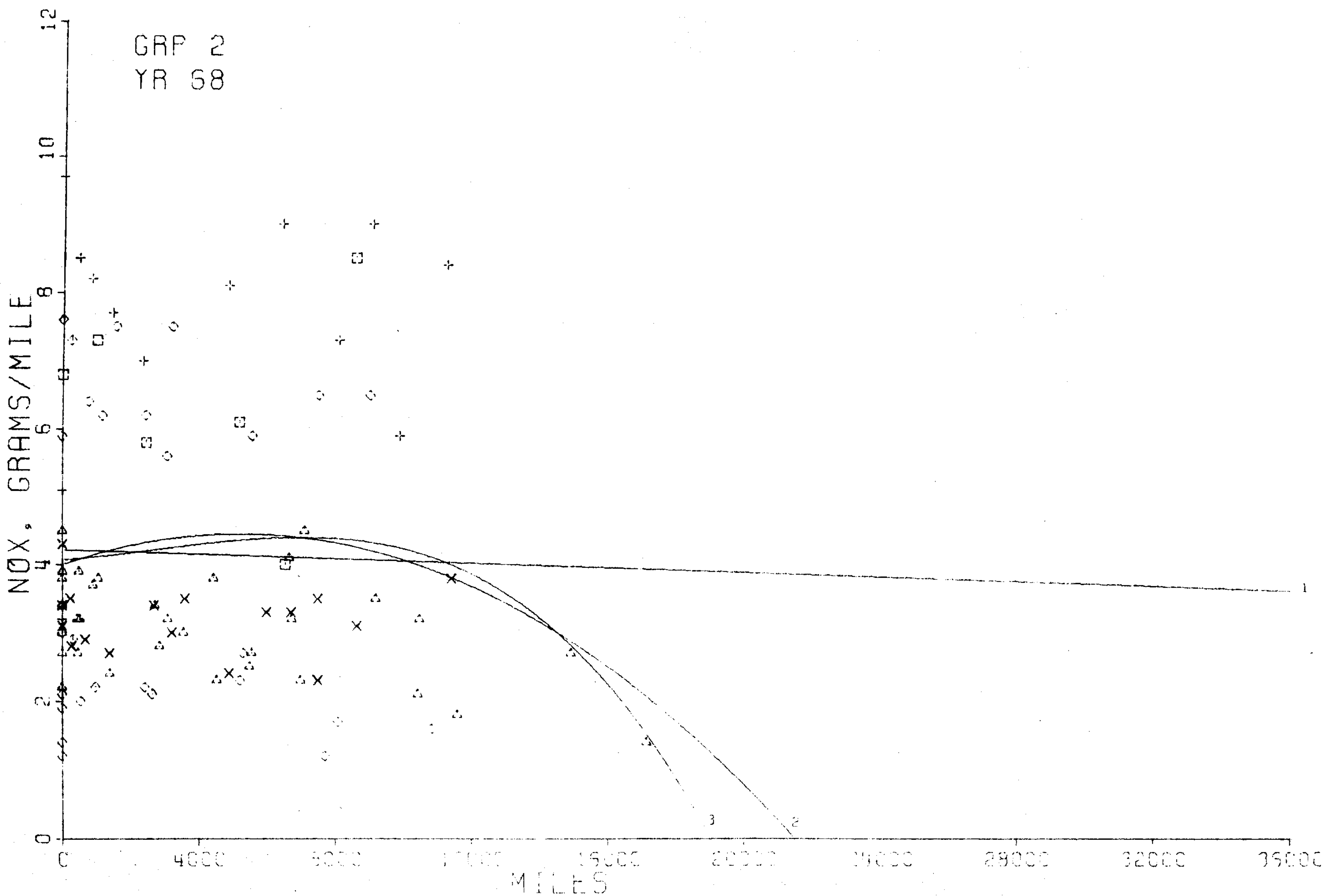

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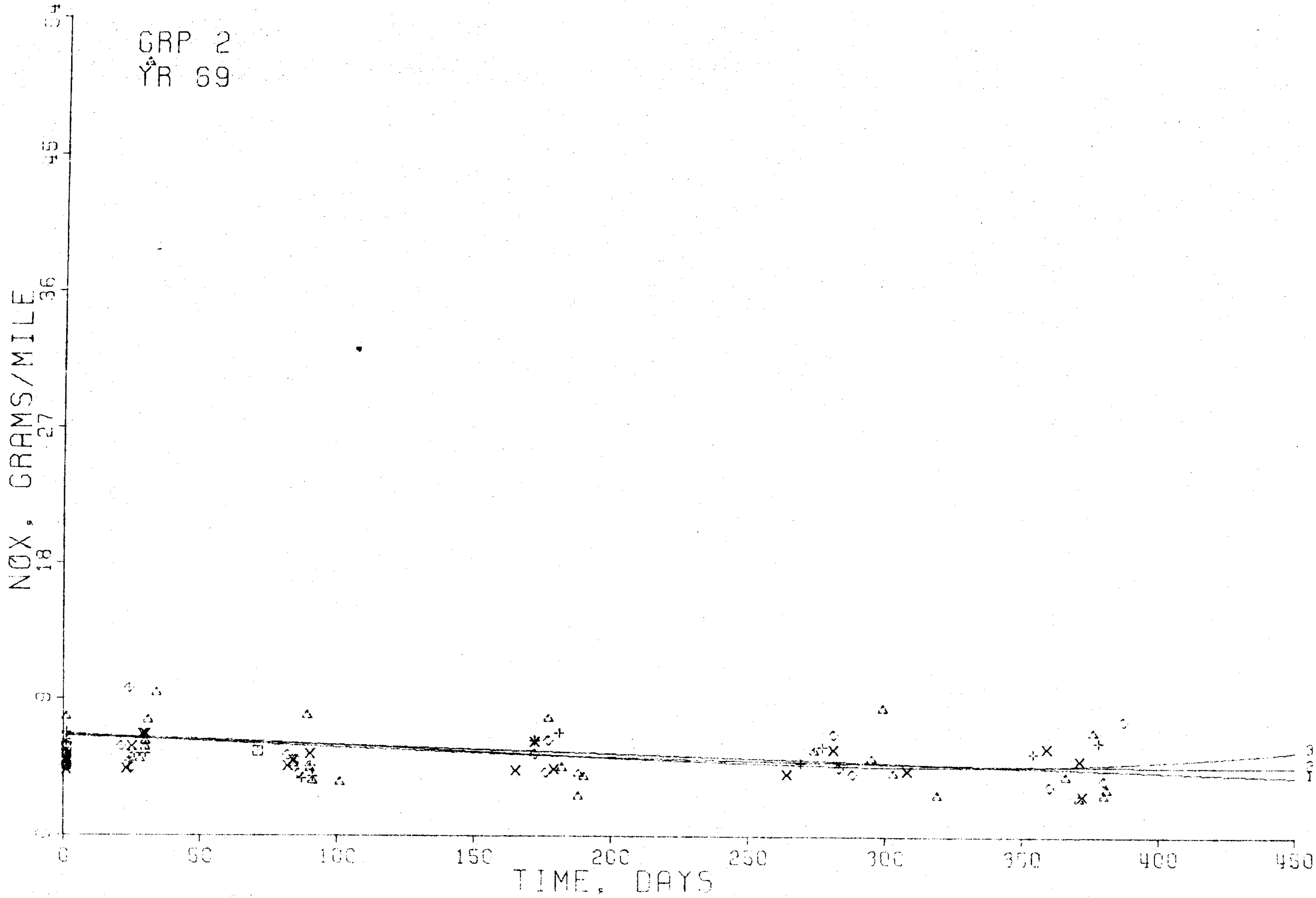

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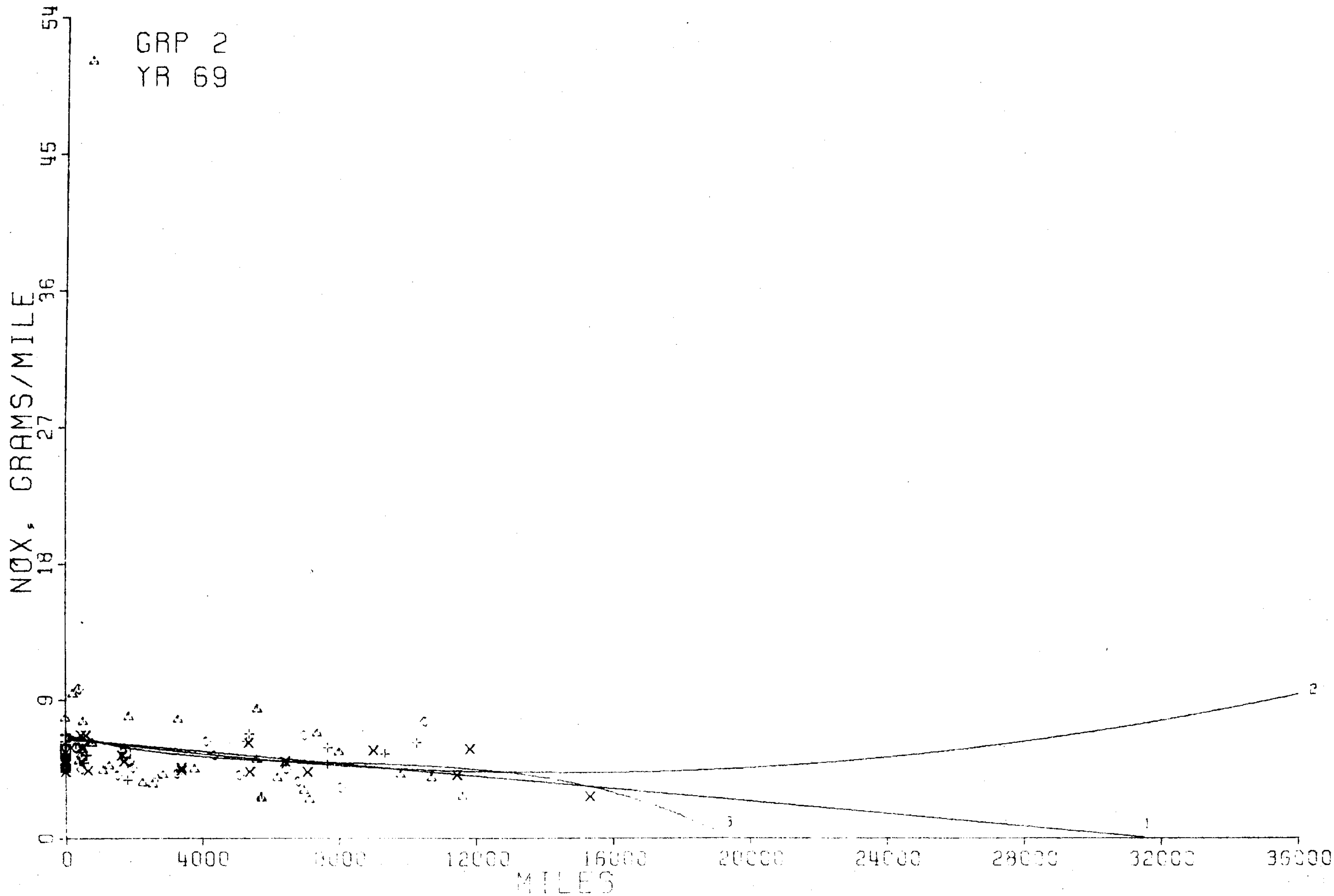

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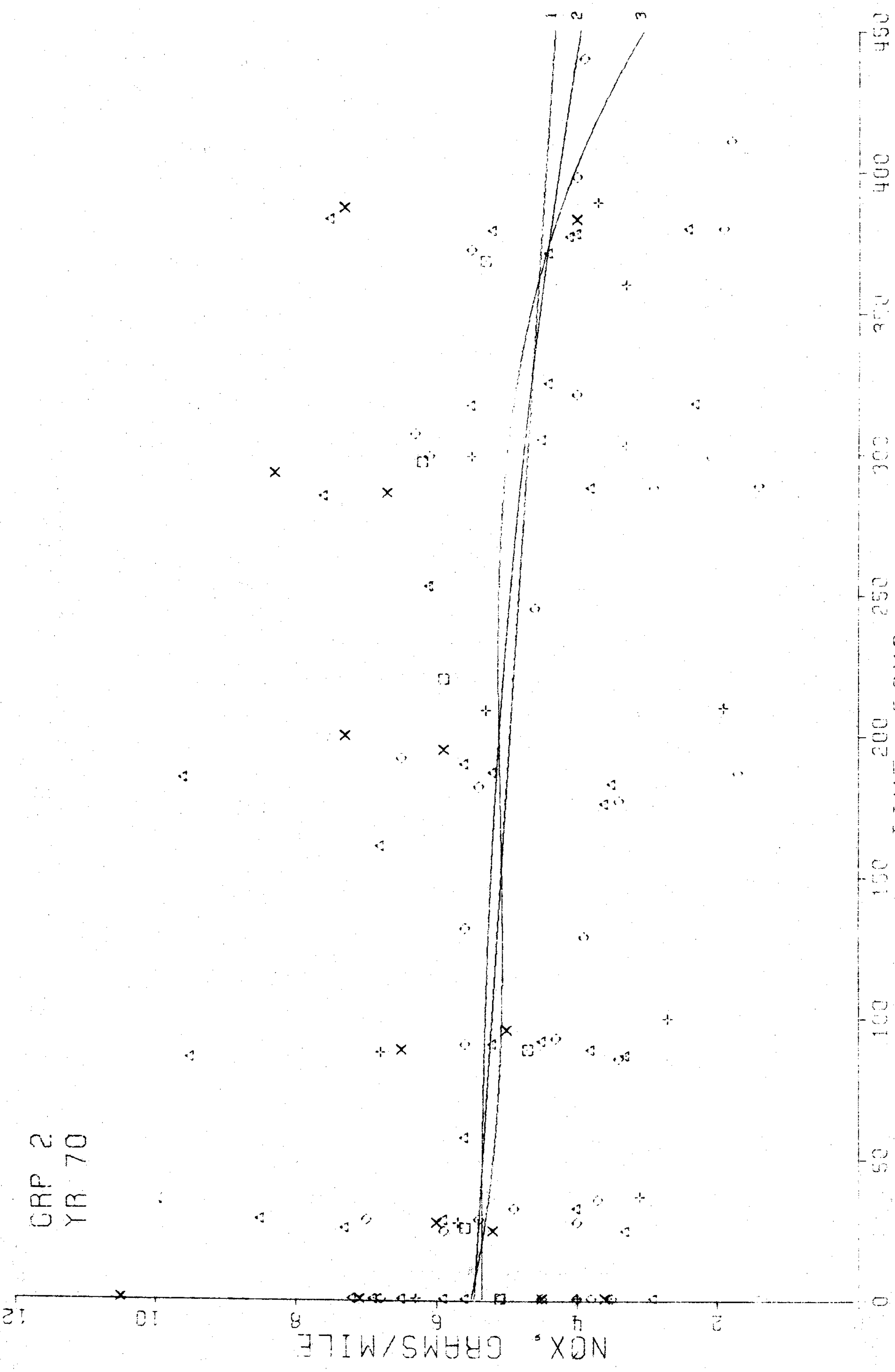

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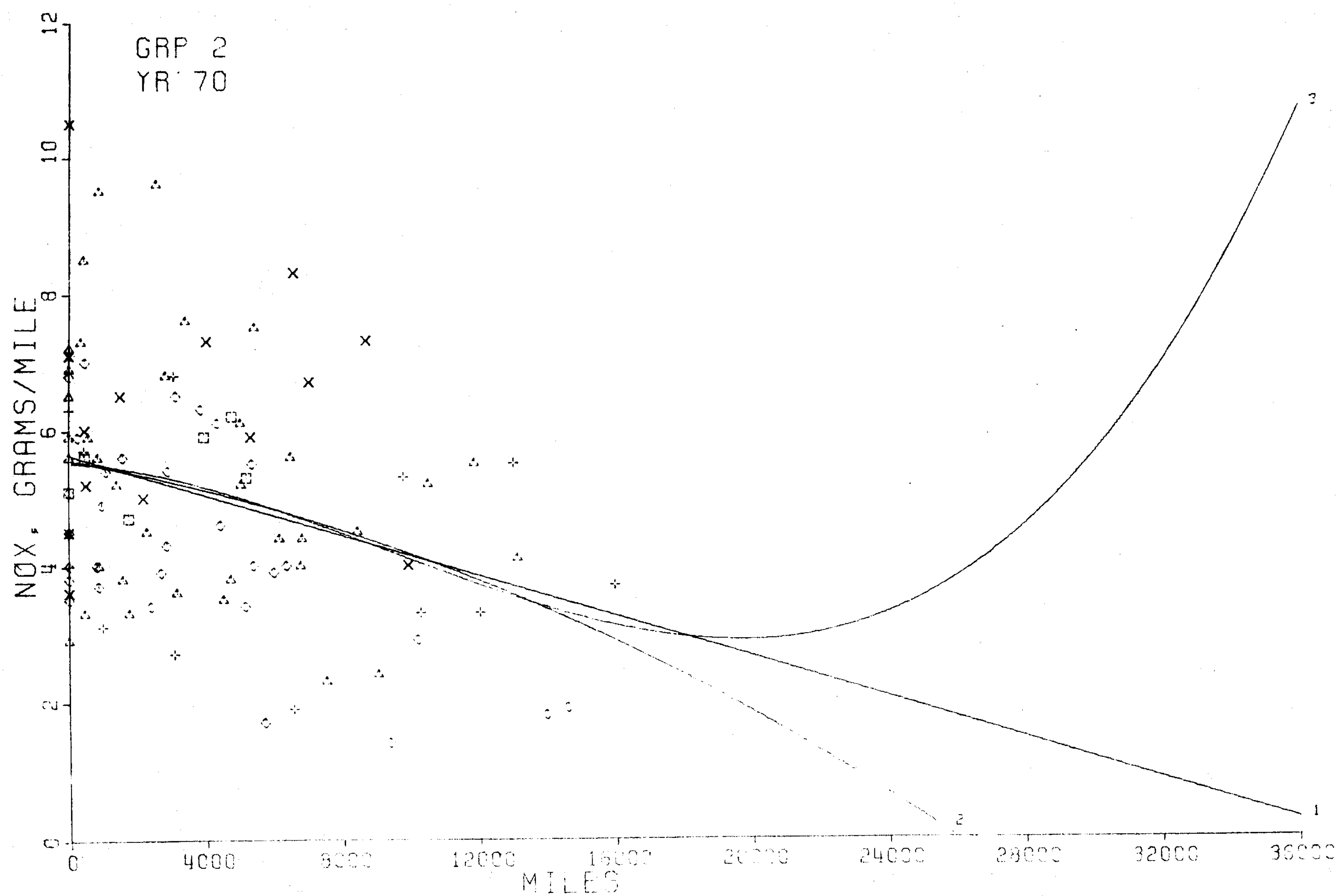

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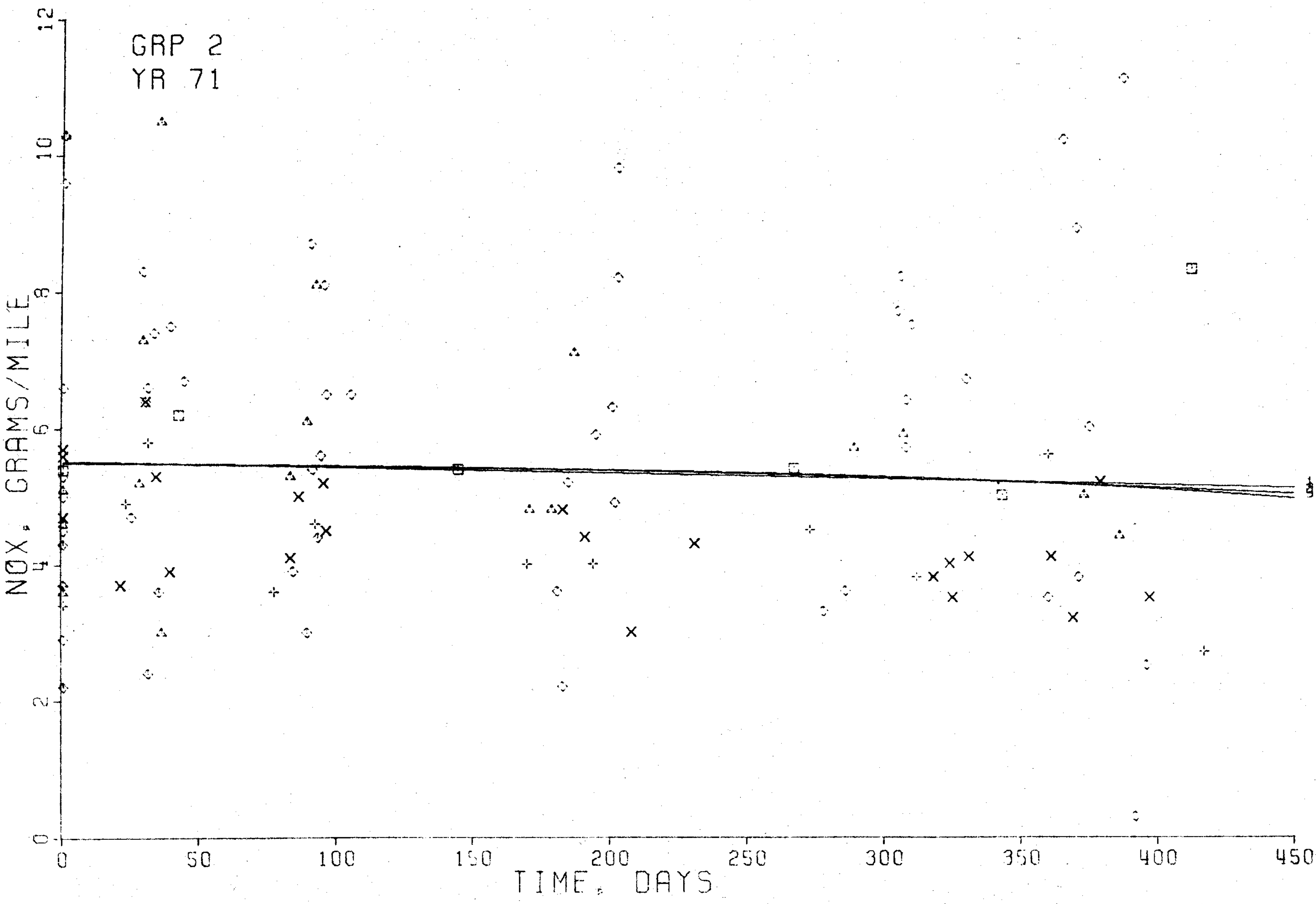

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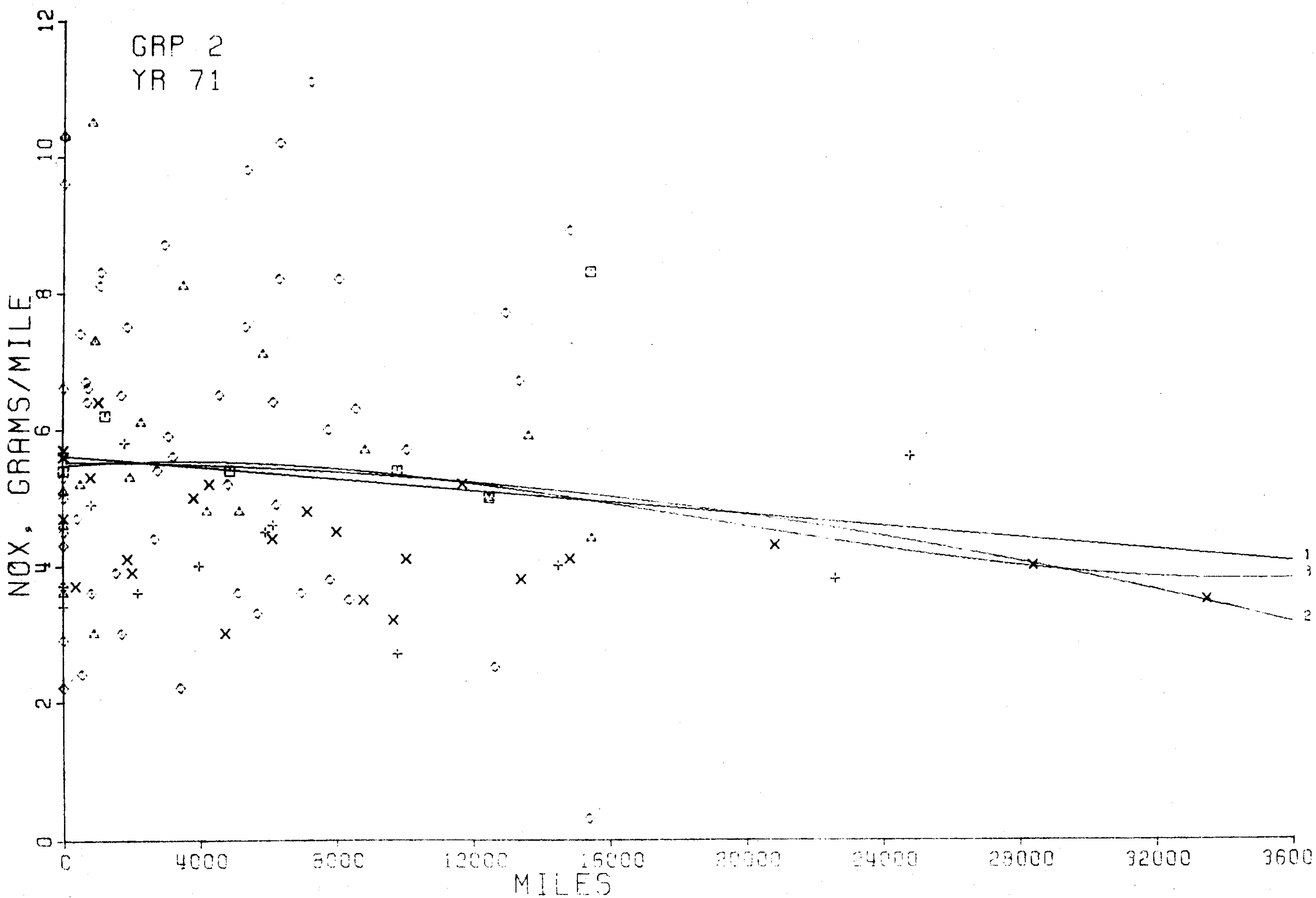

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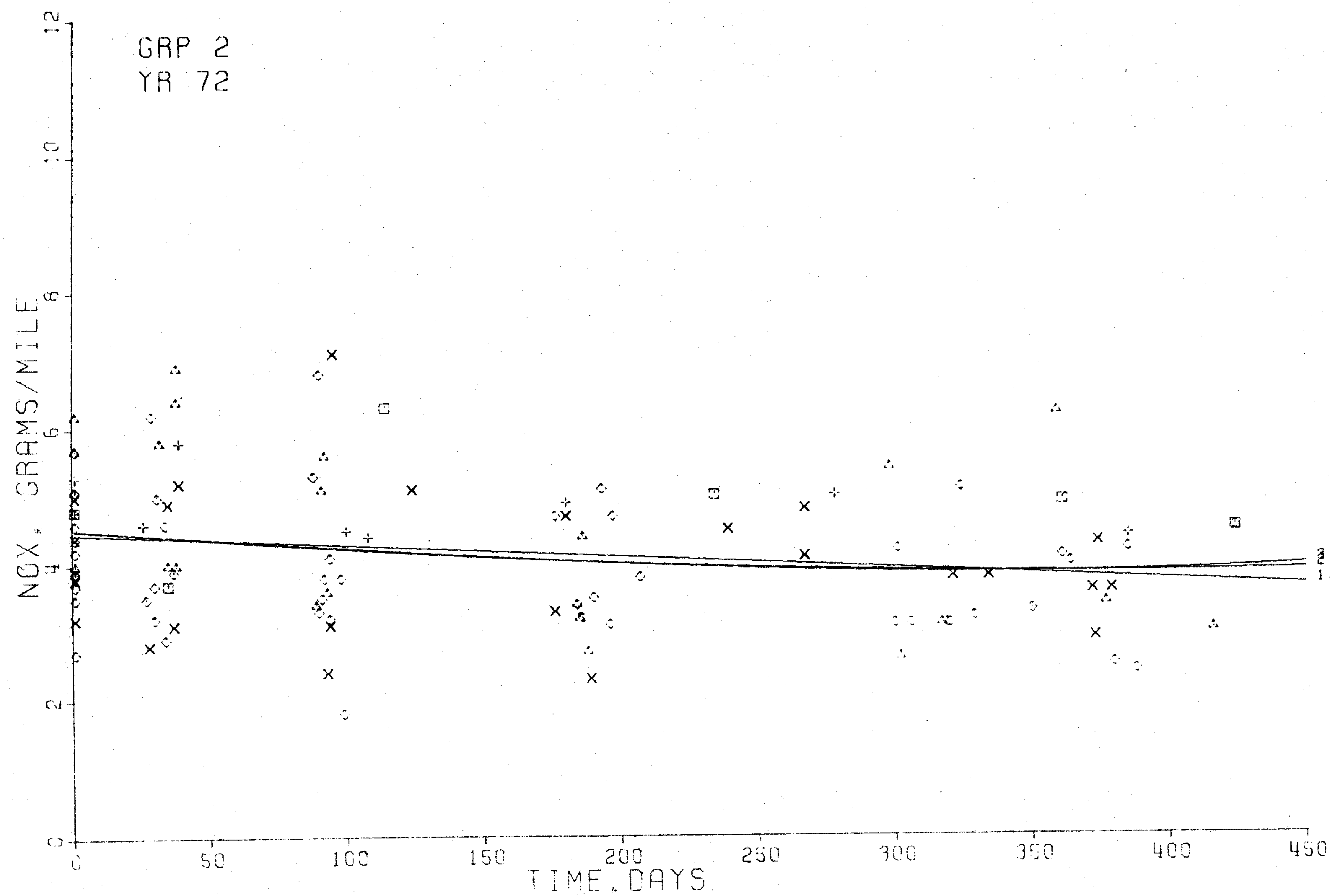

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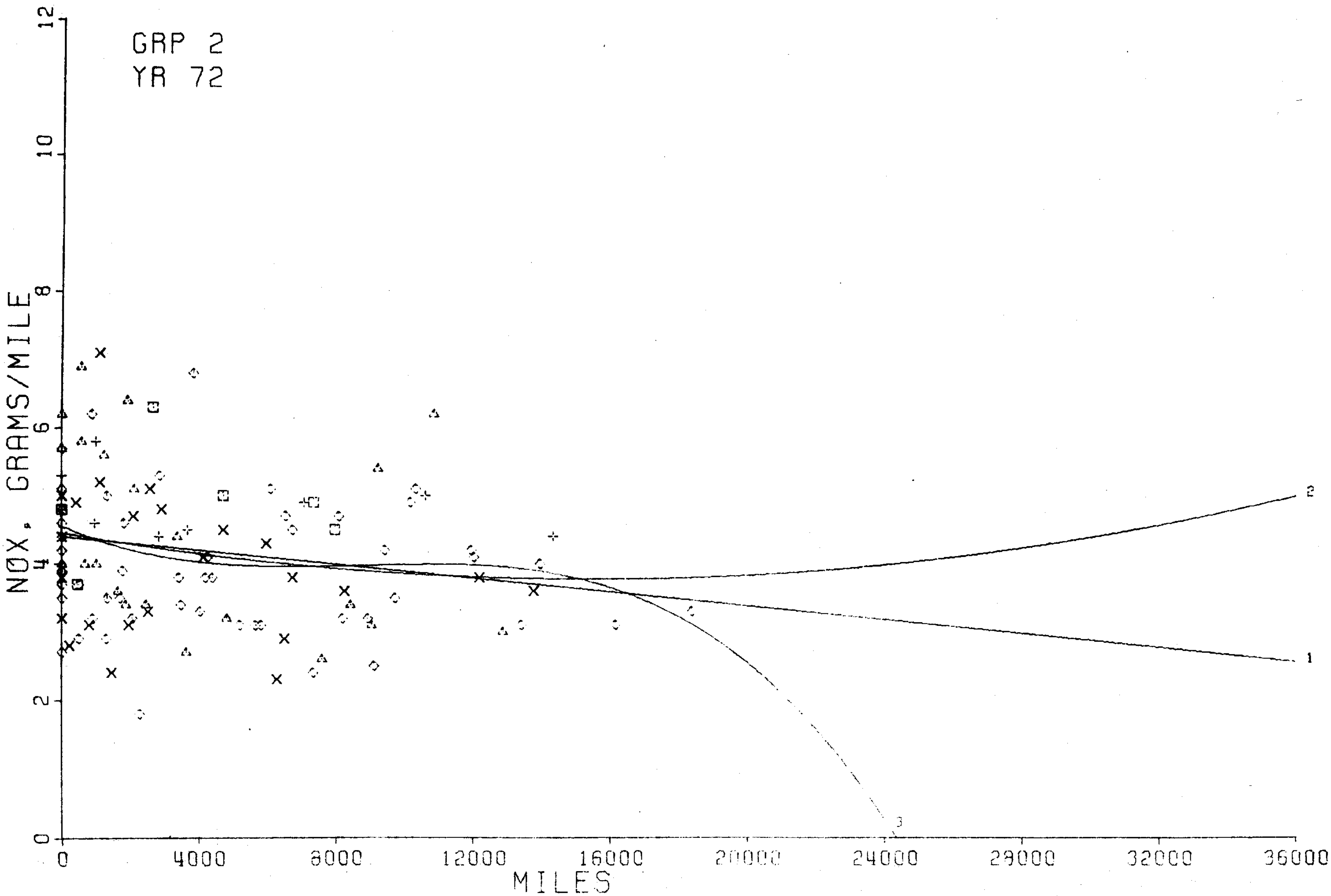

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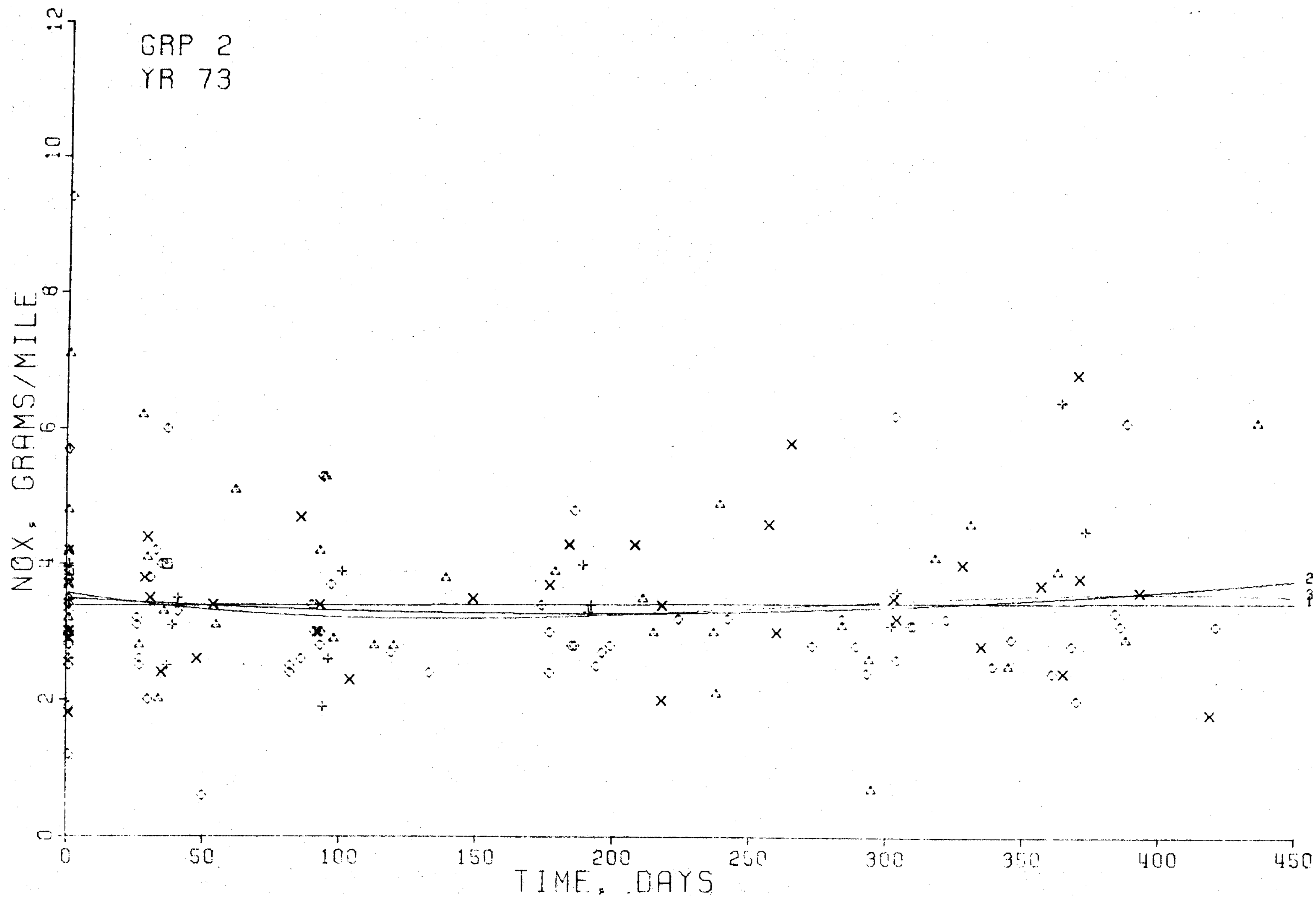

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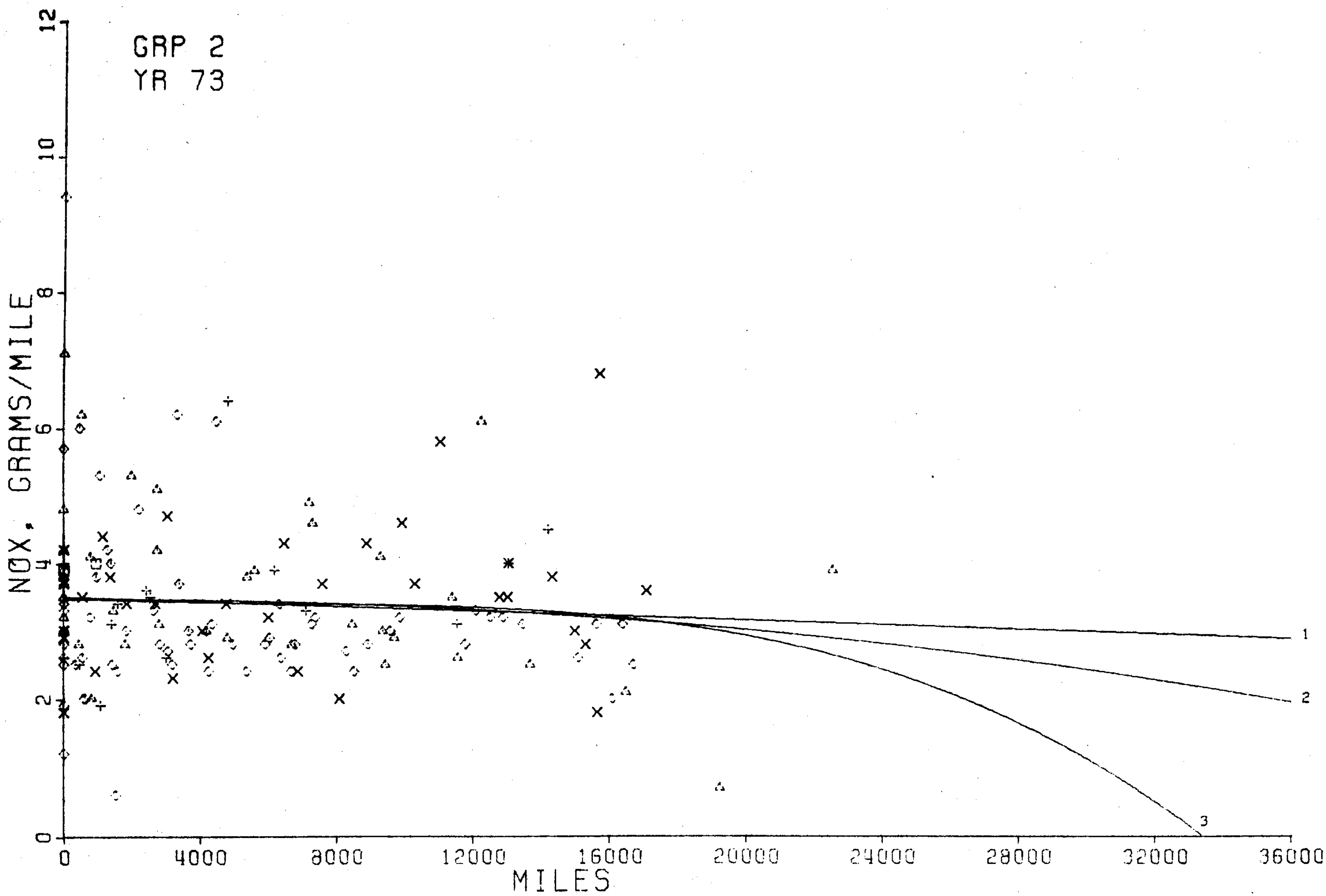

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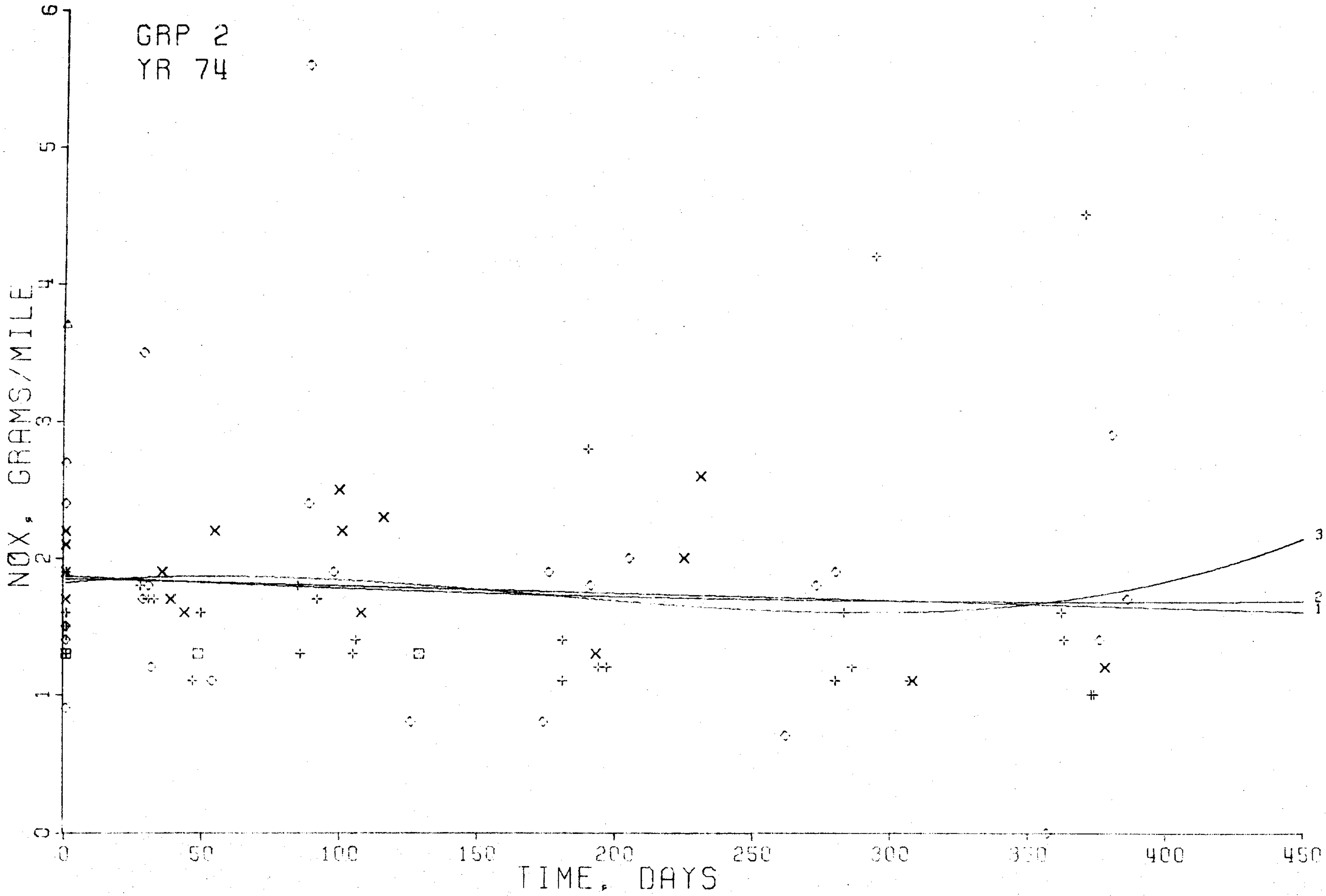

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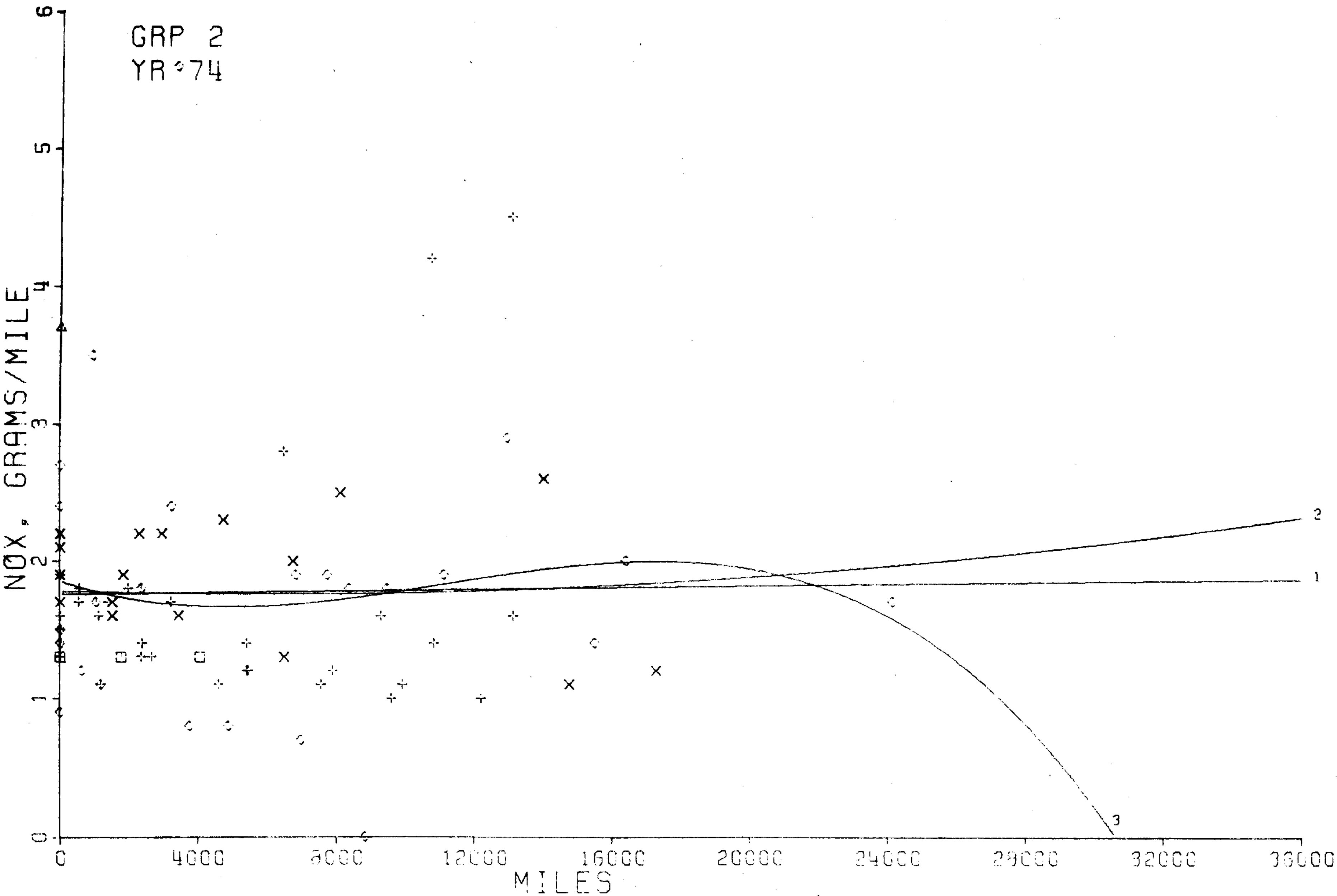

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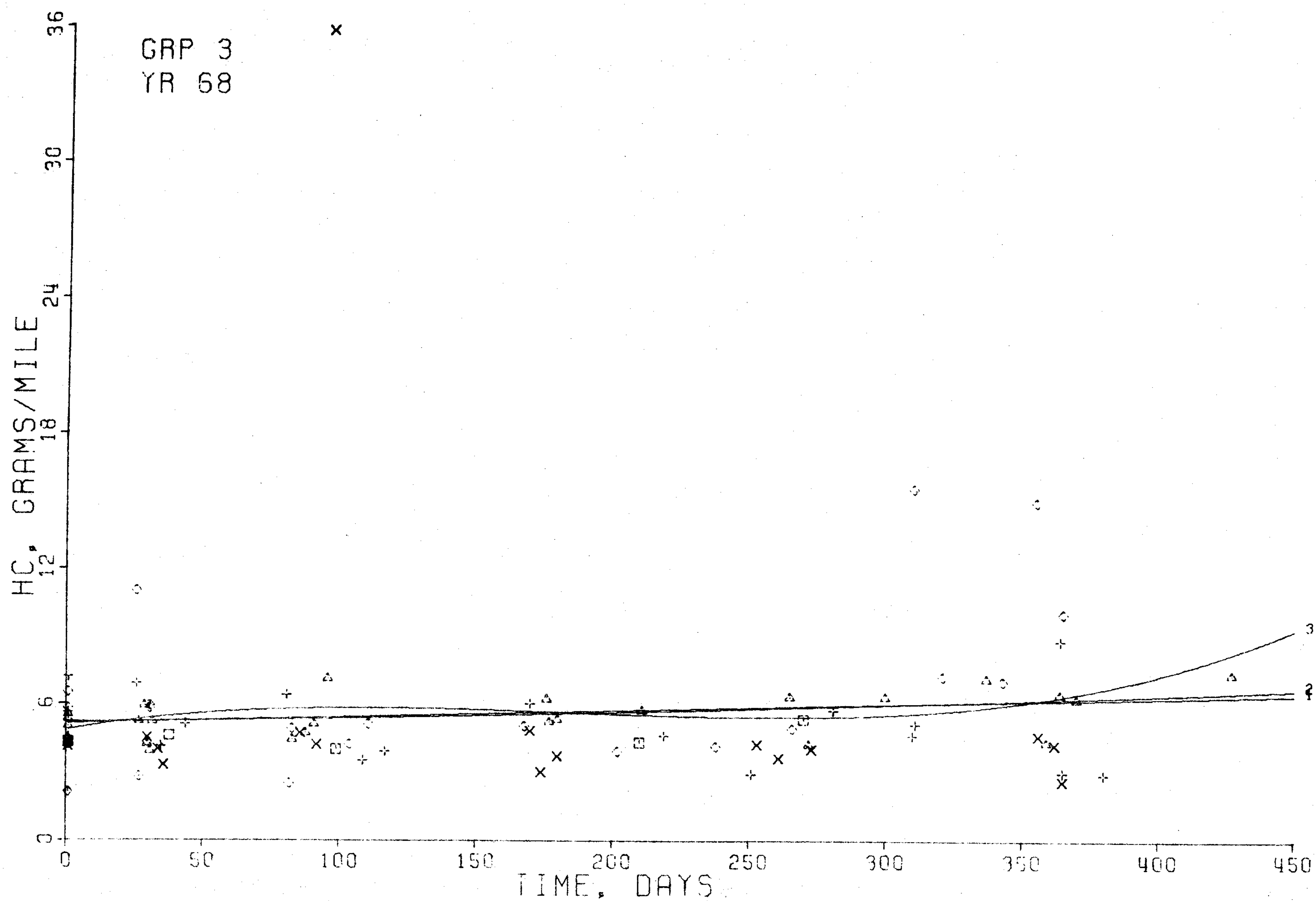

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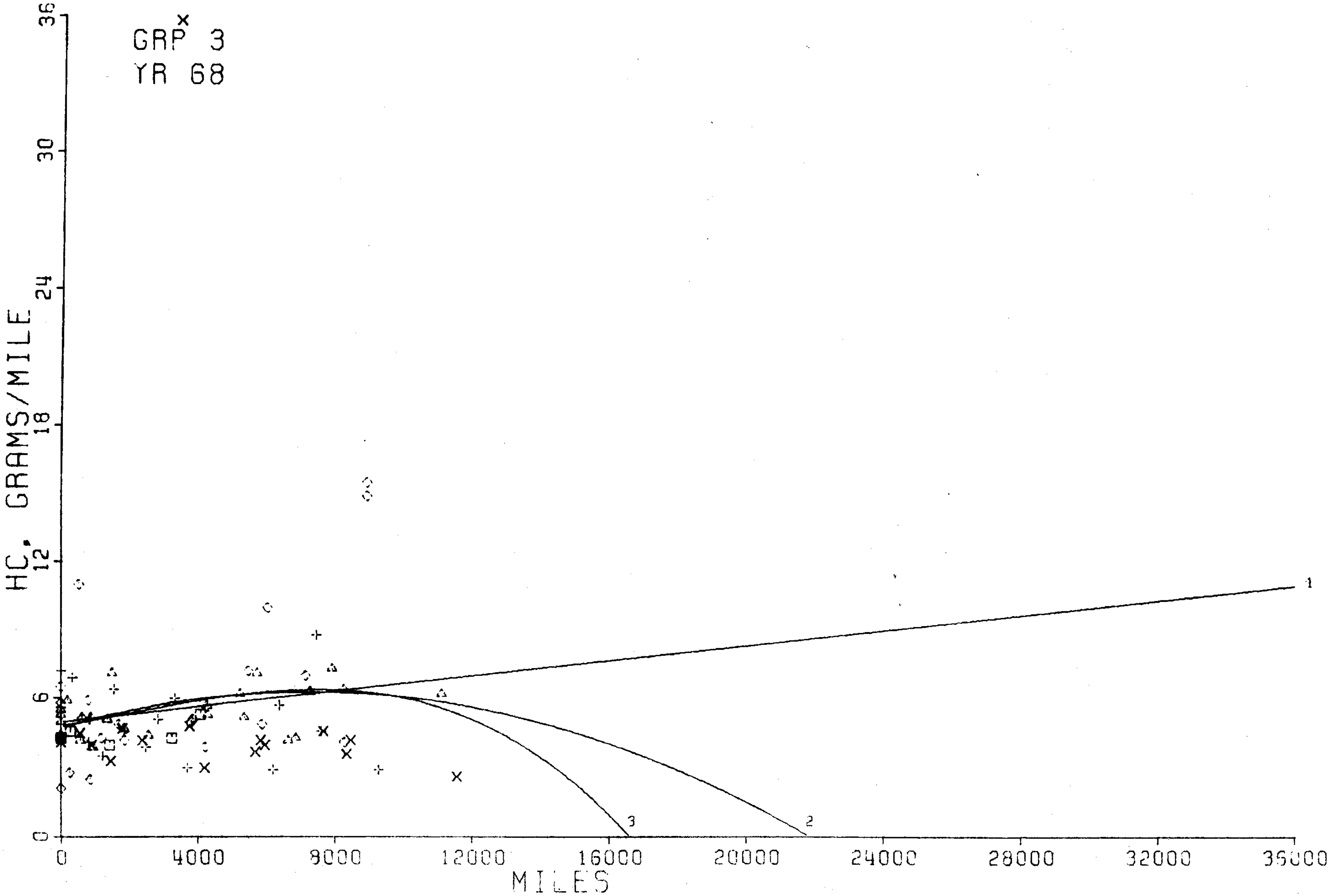

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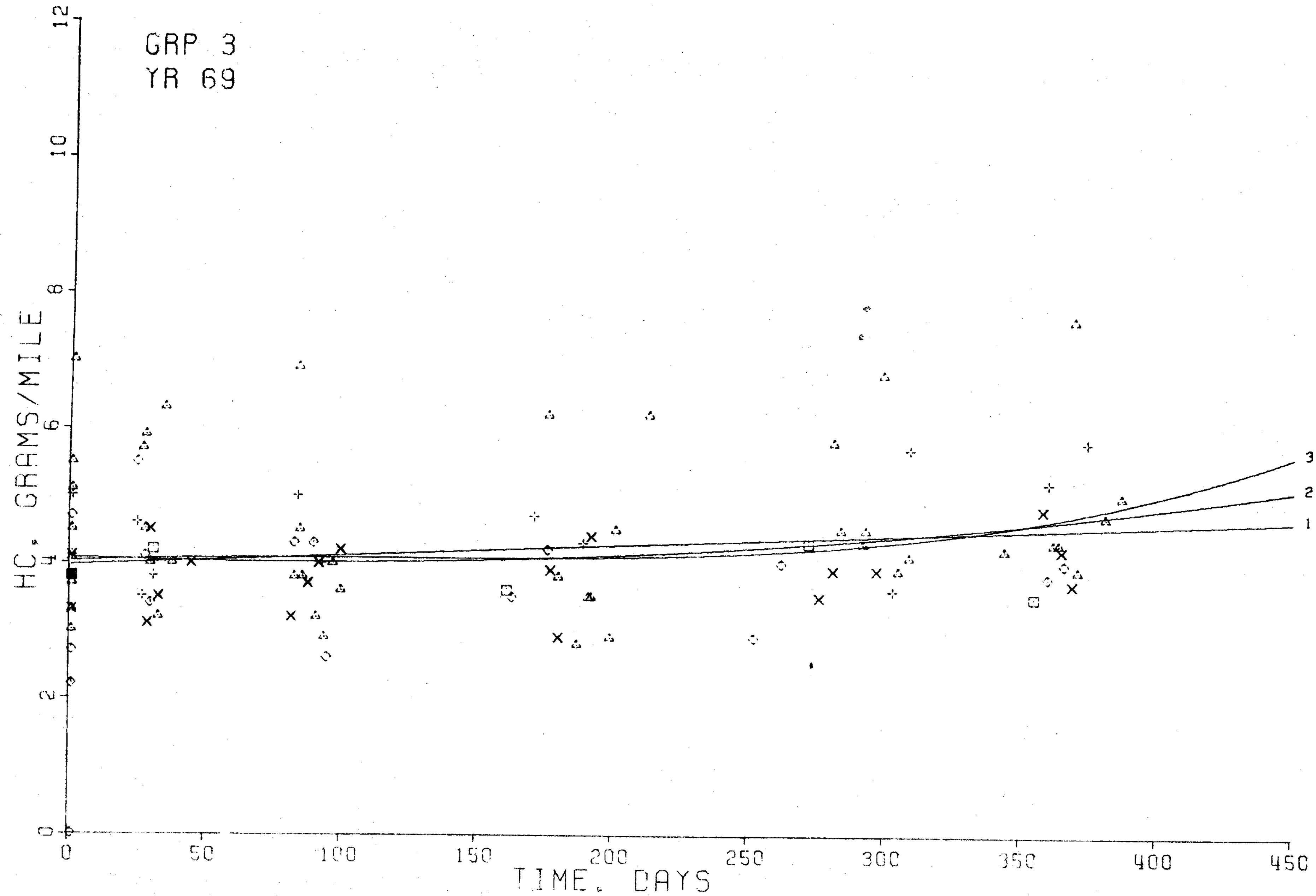

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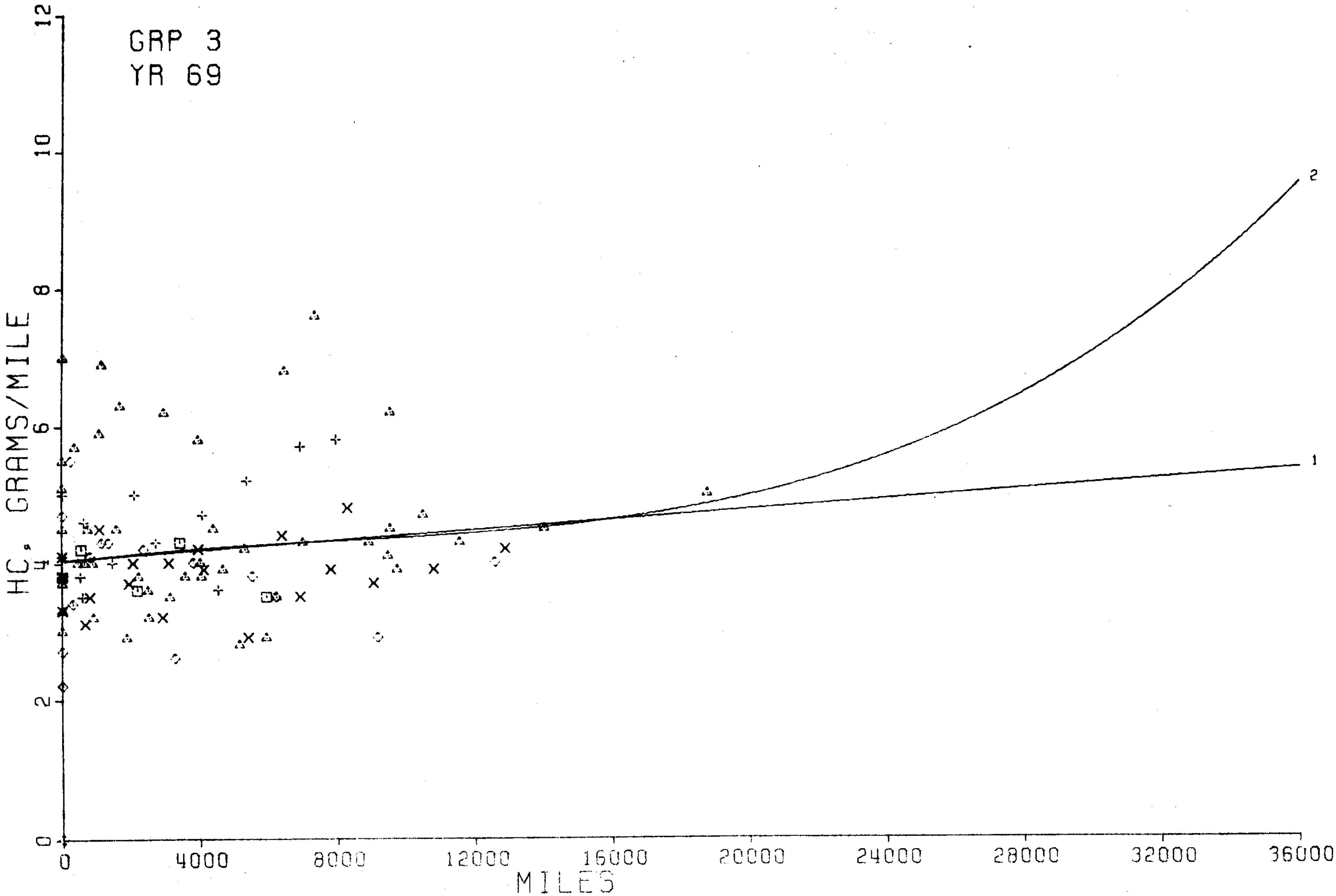

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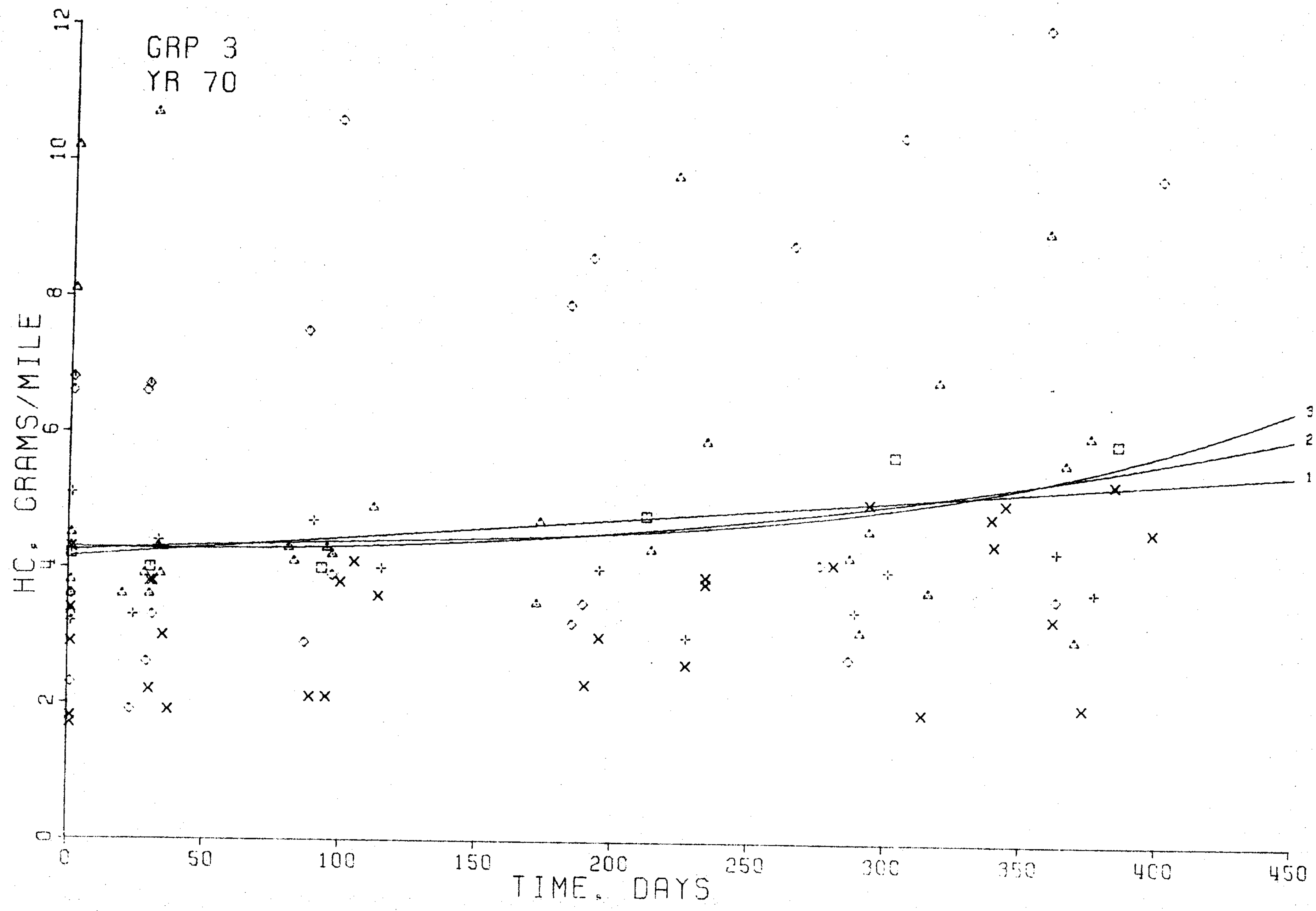

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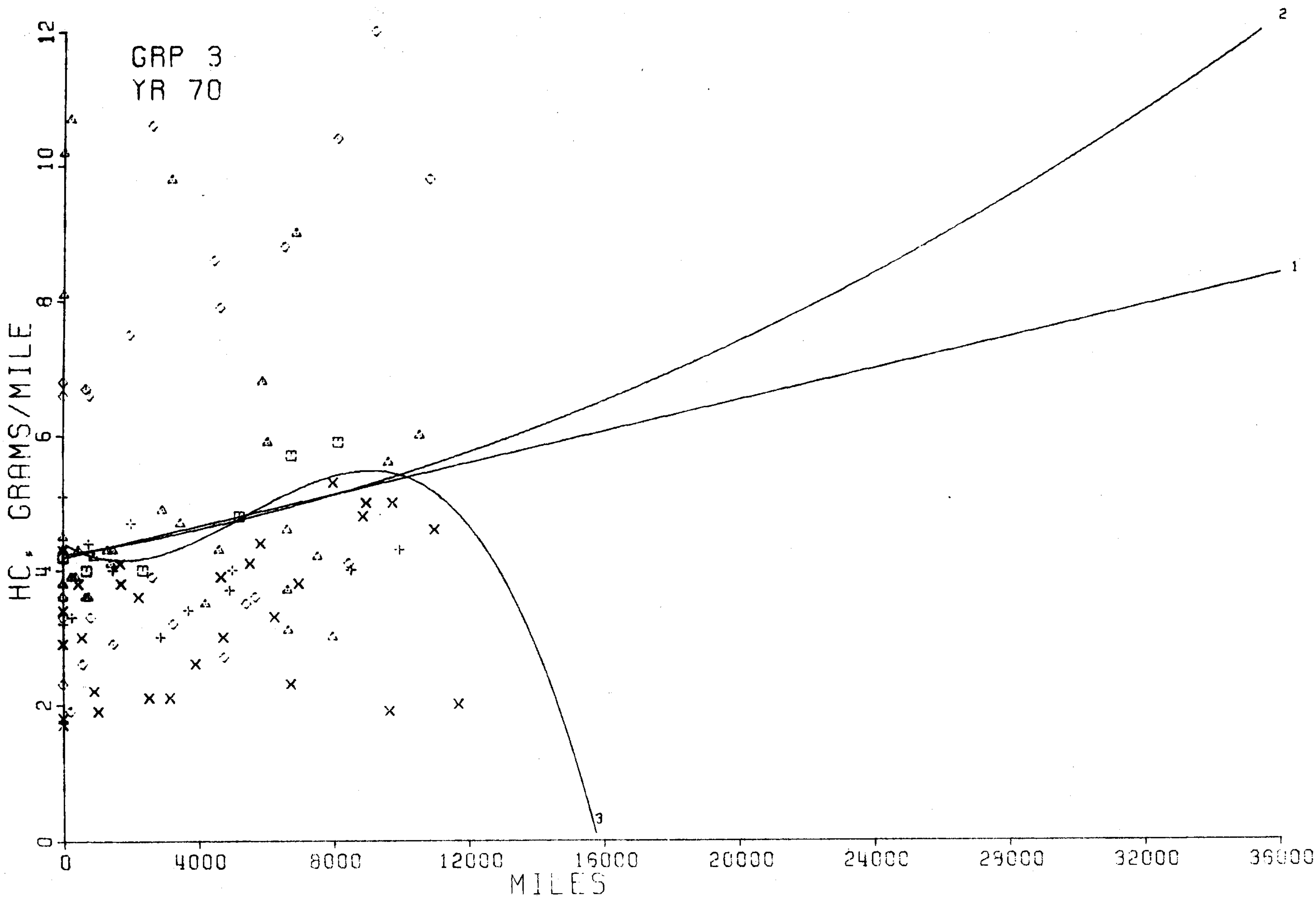

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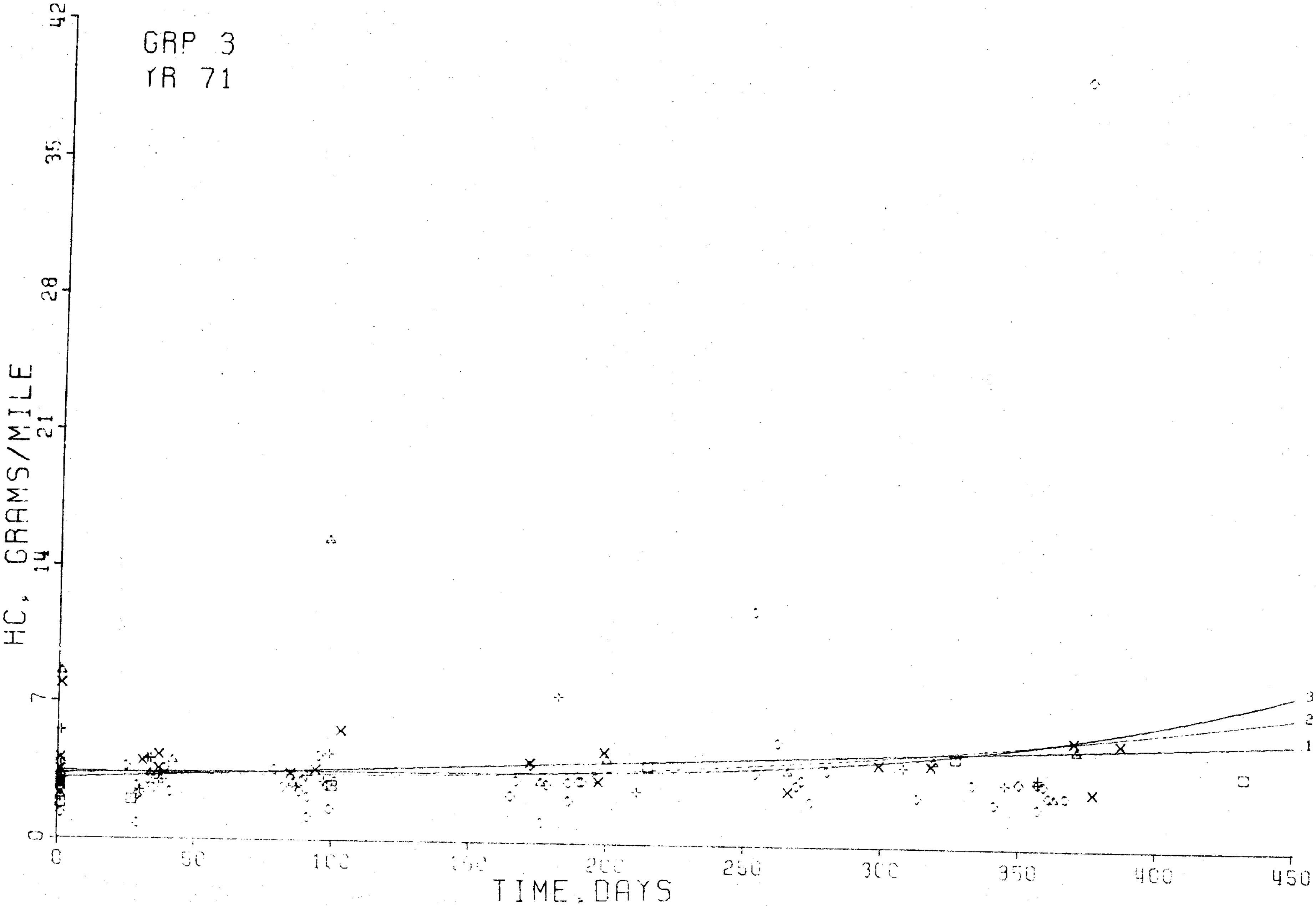

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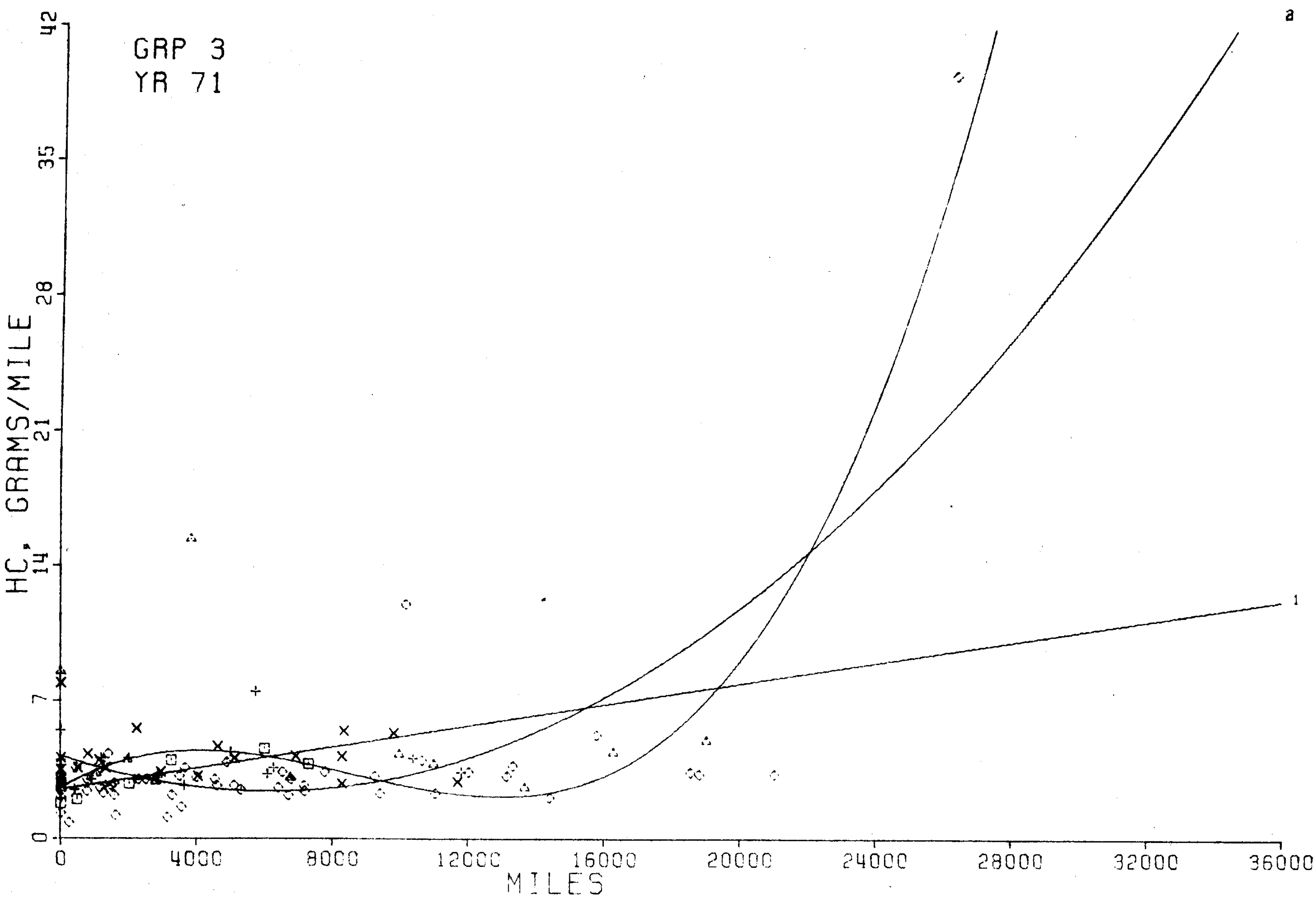

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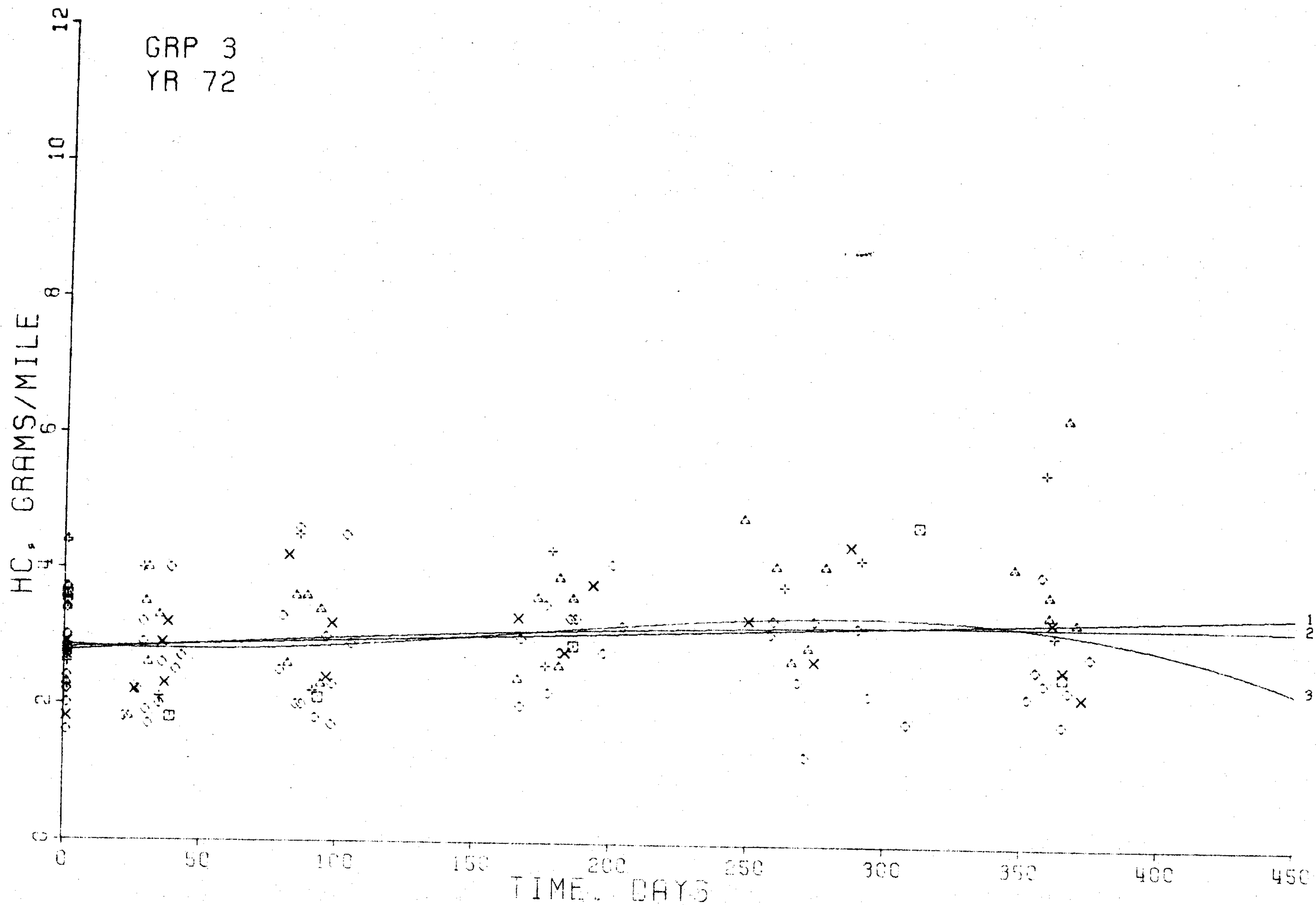

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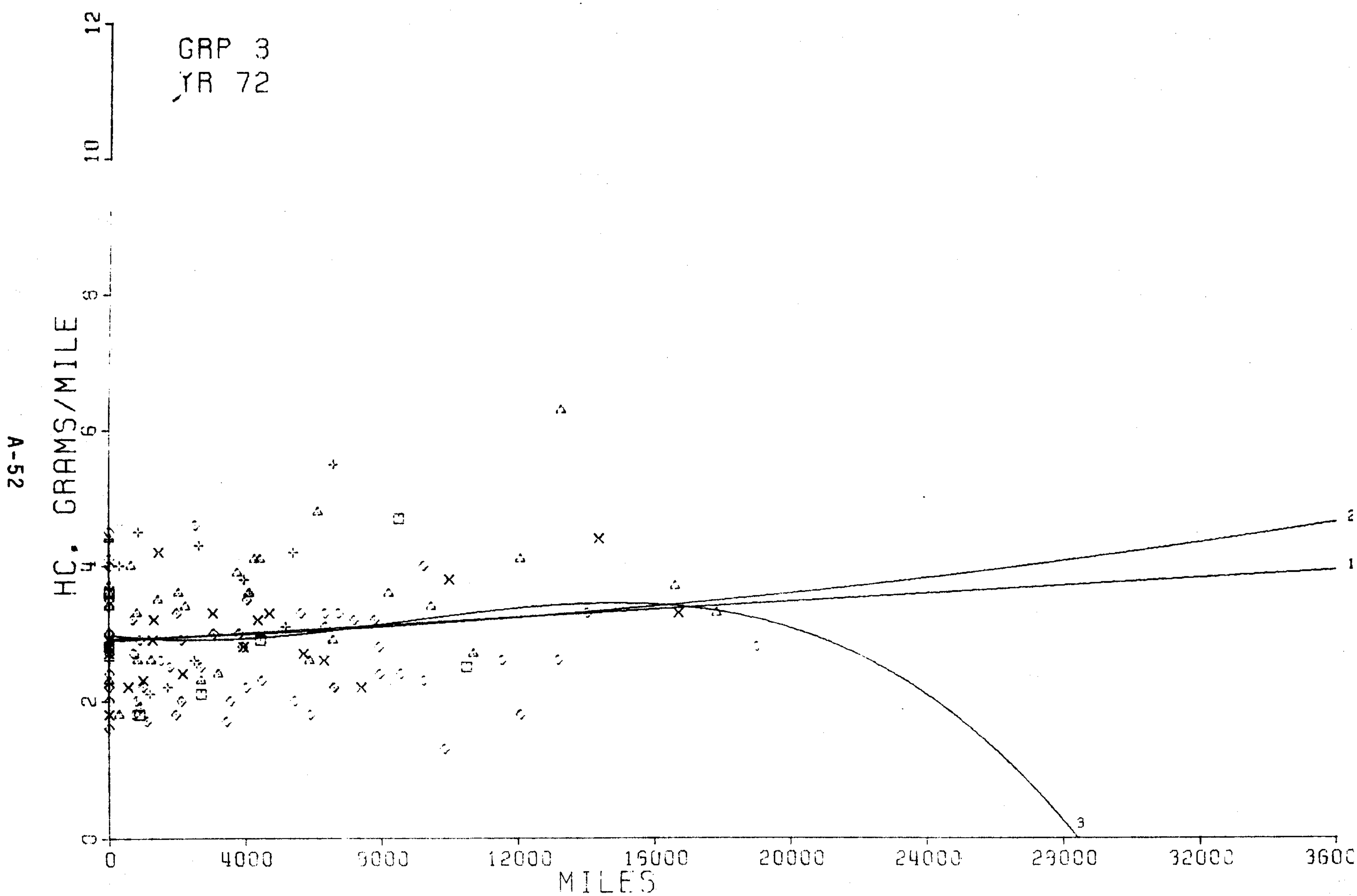

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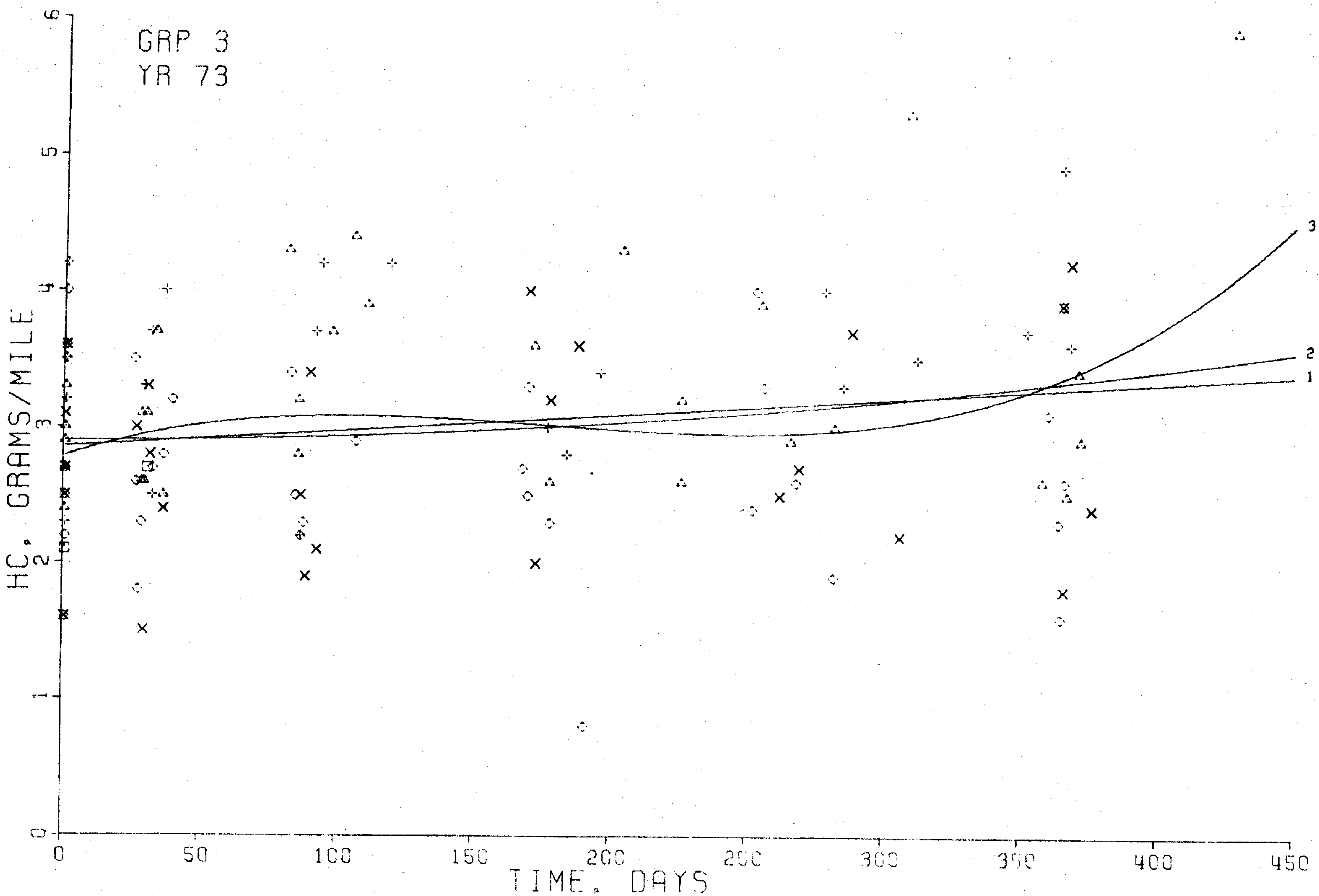

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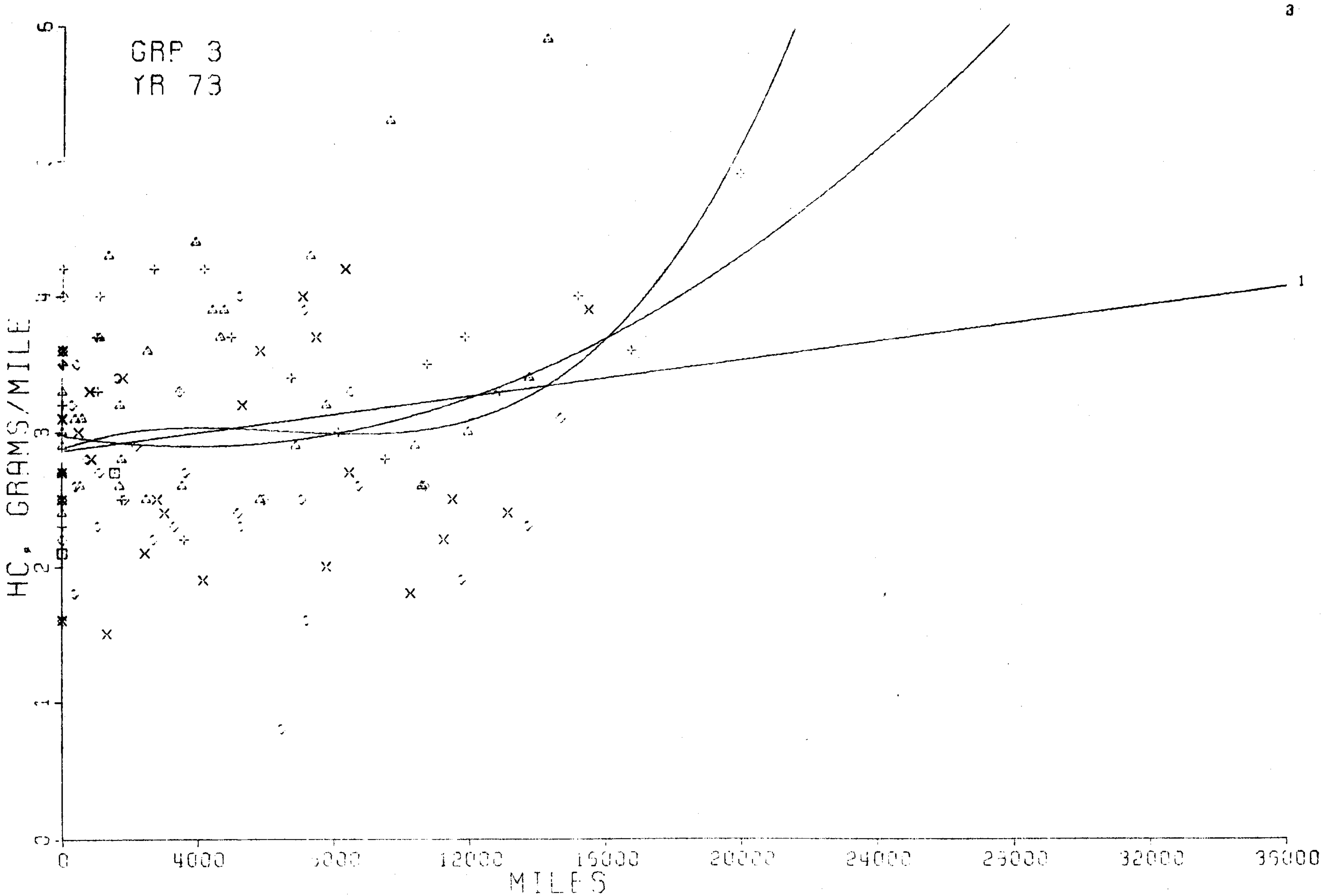

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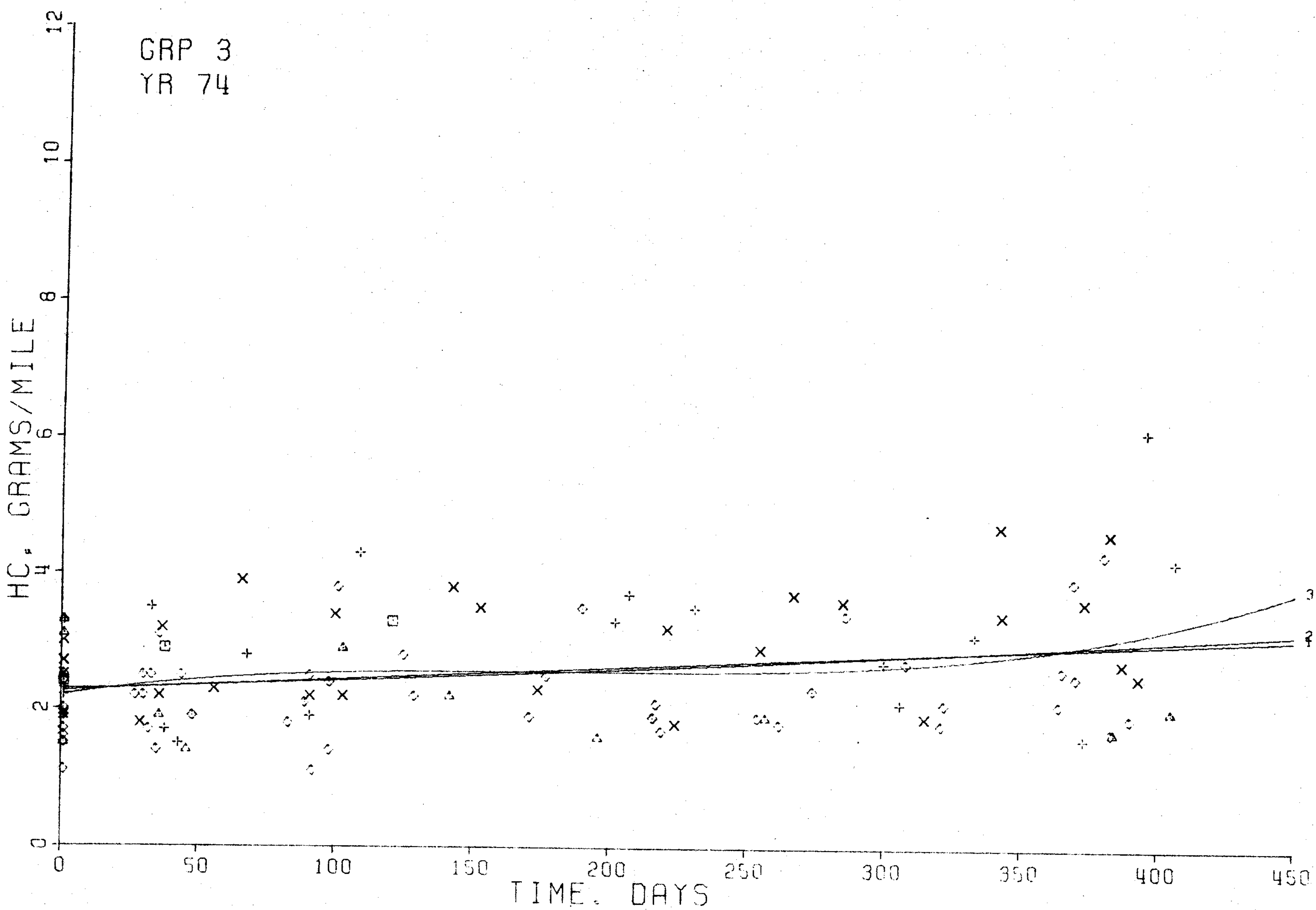

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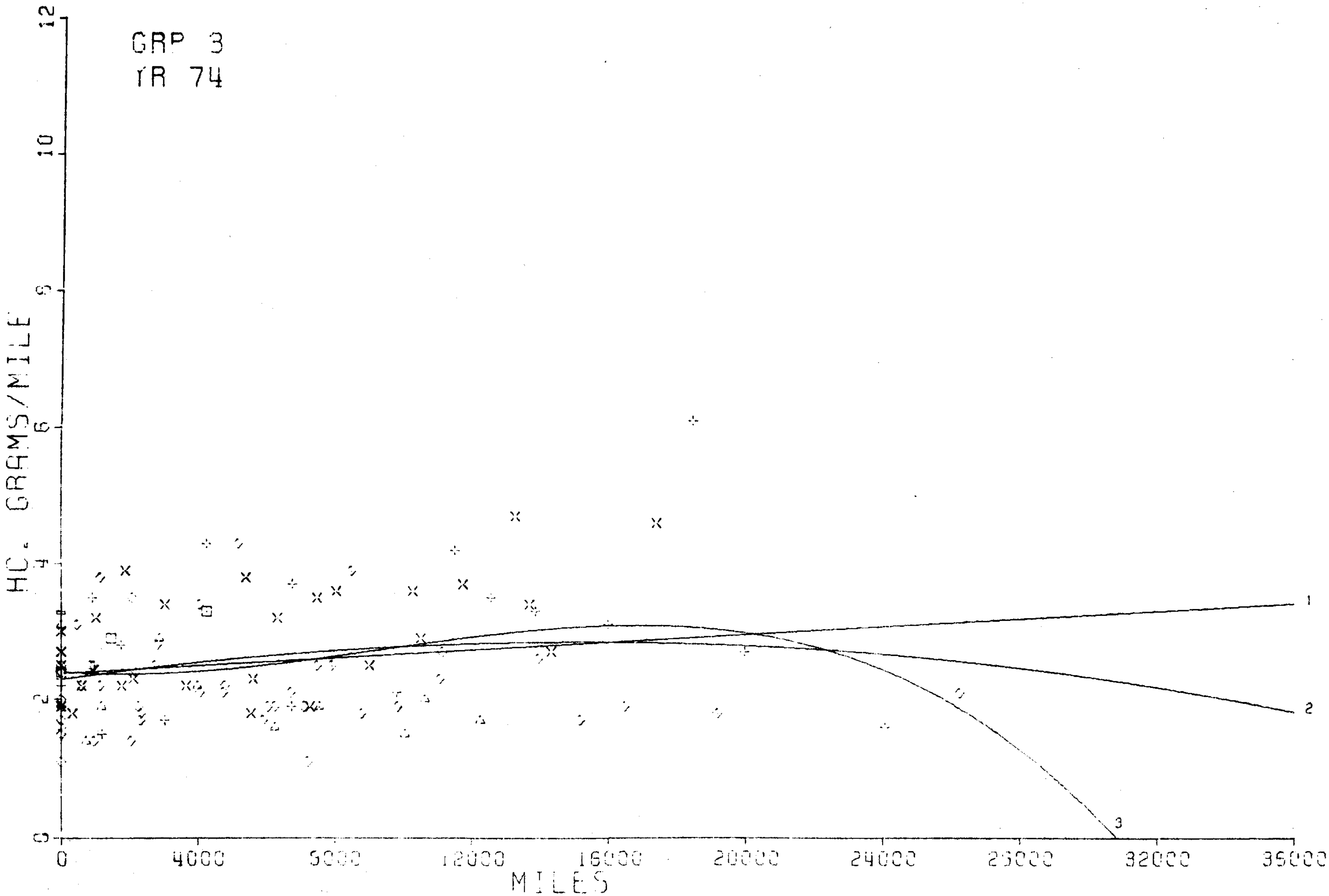


Figure A-56. DEGRADATION VS. MILES

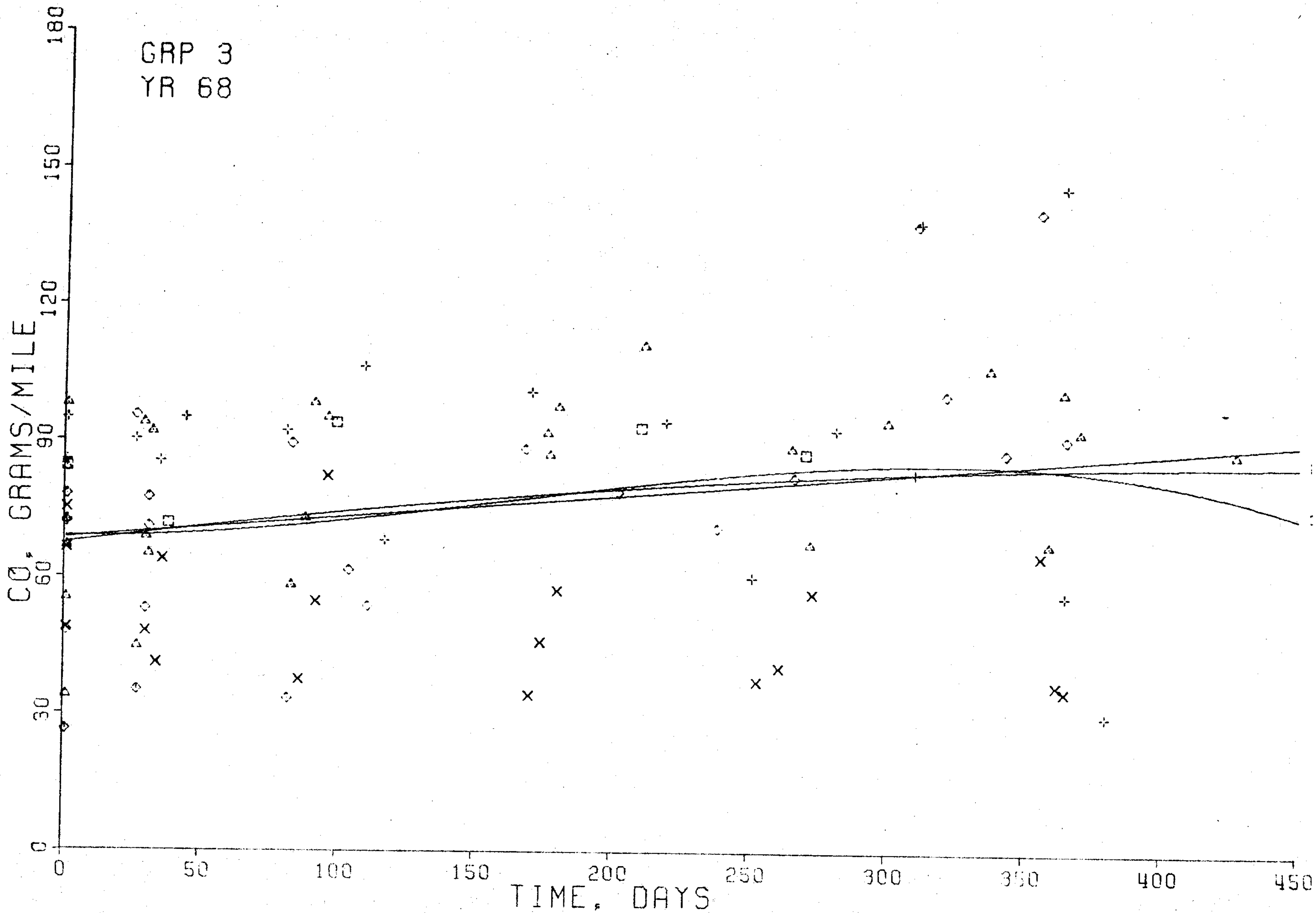


Figure A-57. DEGRADATION VS. TIME

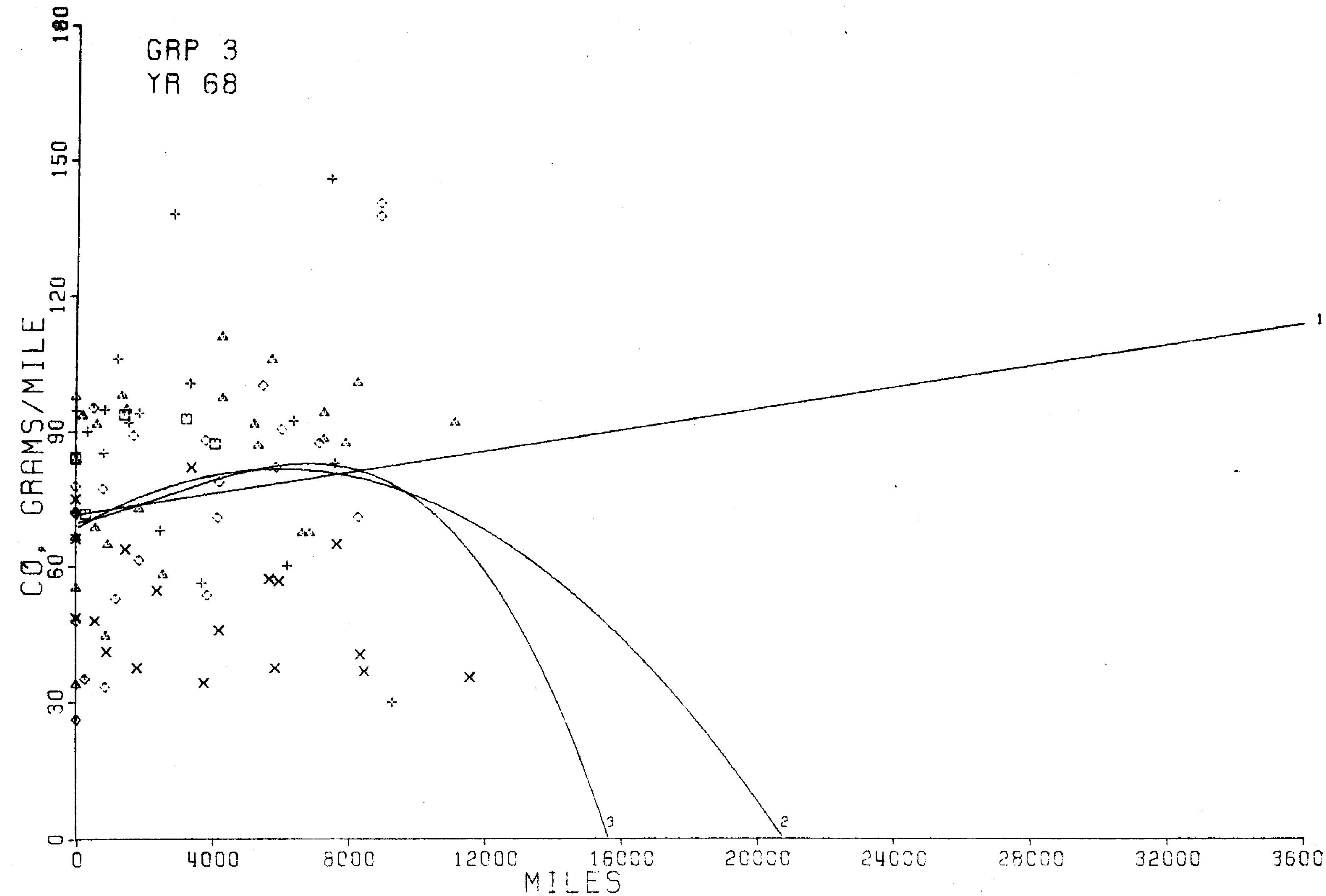


Figure A-58. DEGRADATION VS. MILES

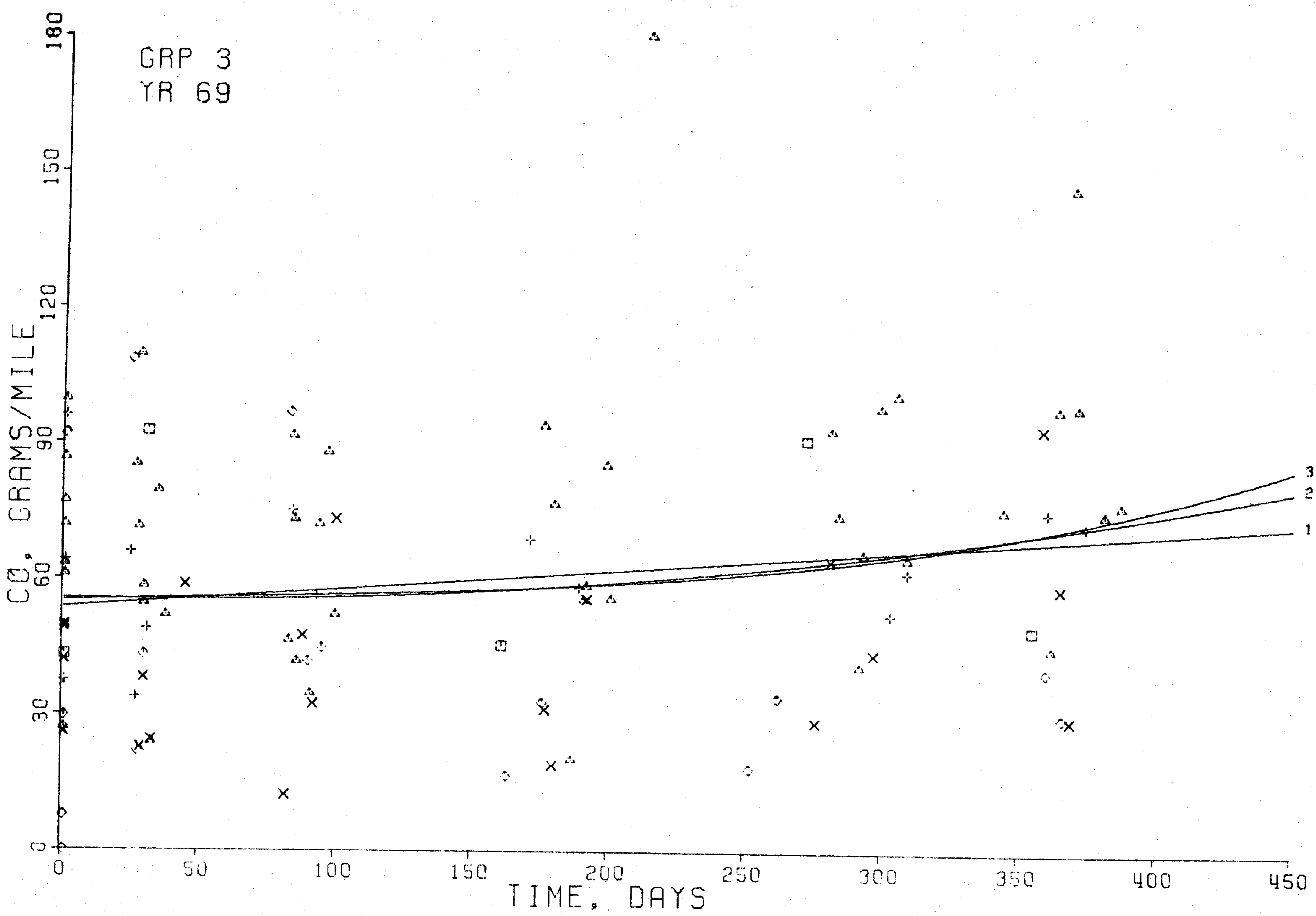


Figure A-59. DEGRADATION VS. TIME

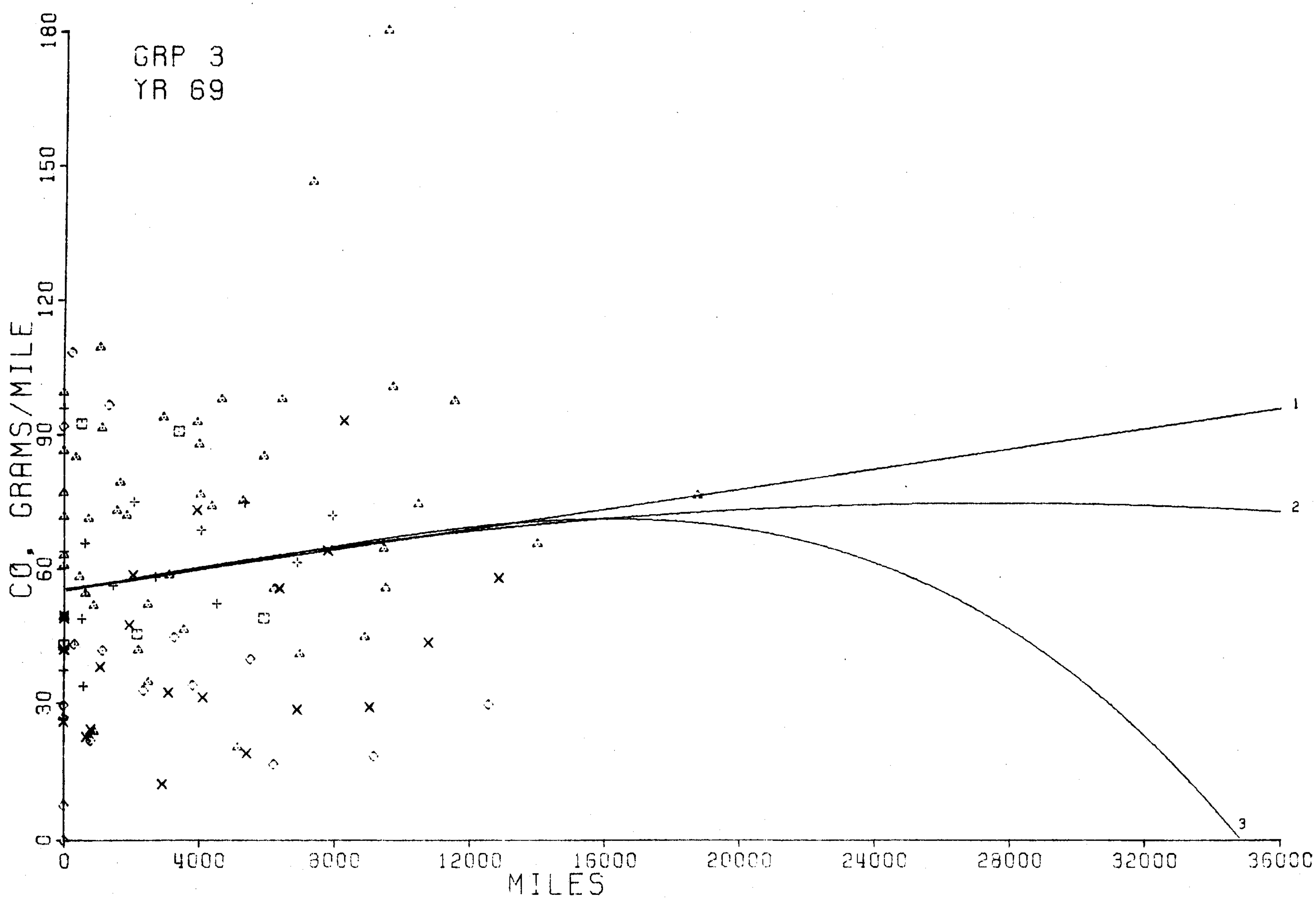


Figure A-60. DEGRADATION VS. MILES

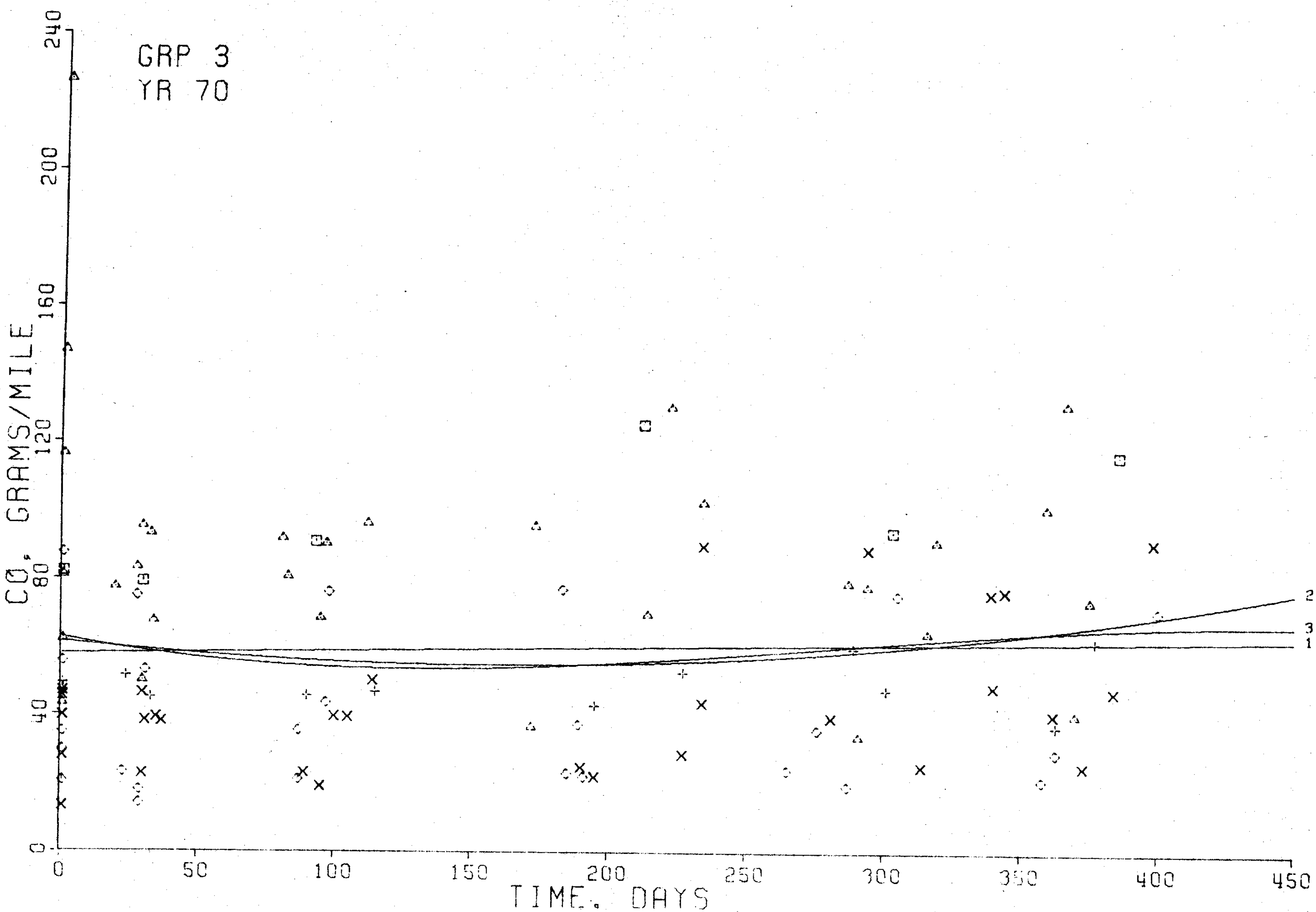


Figure A-61. DEGRADATION VS. TIME

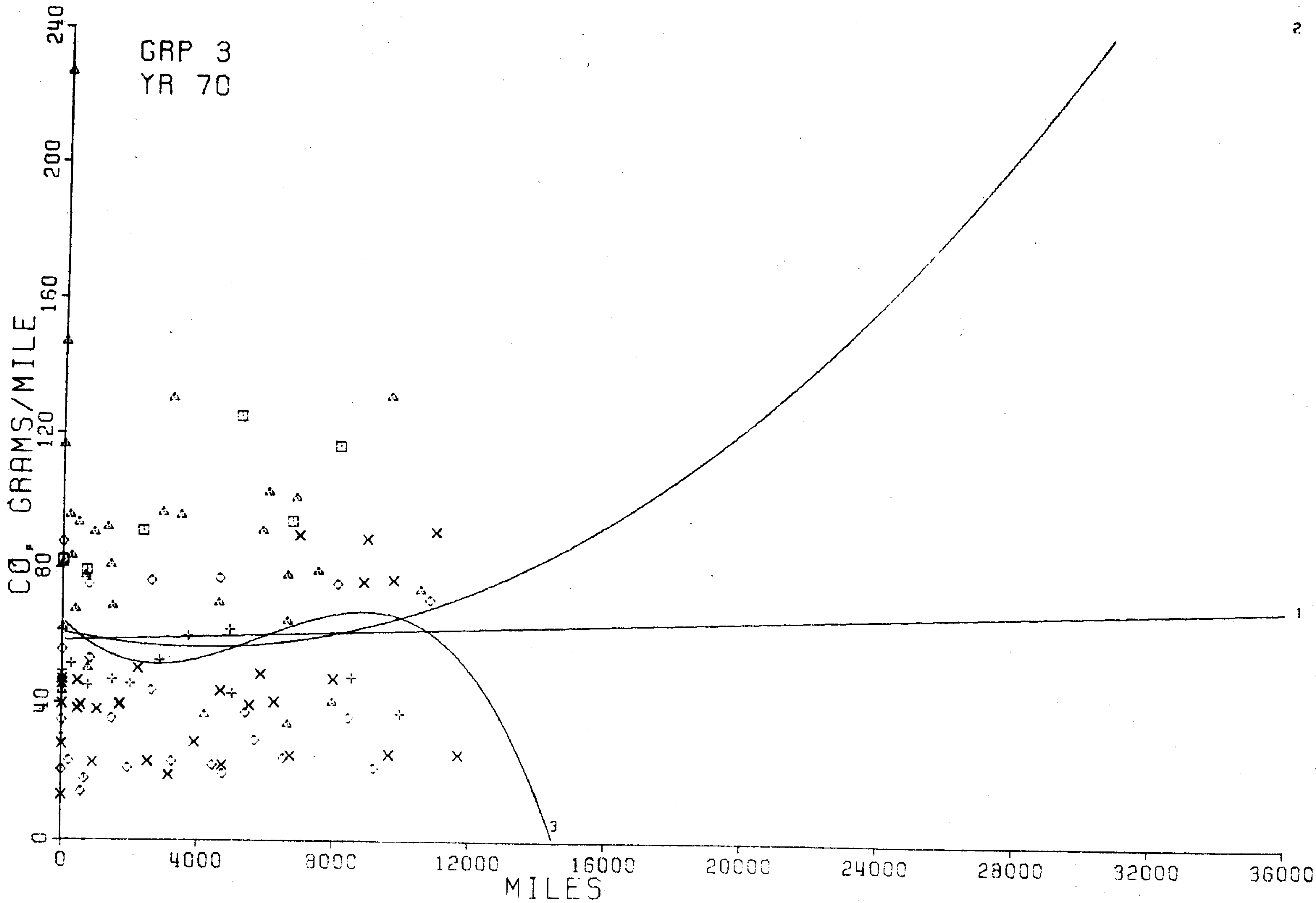


Figure A-62. DEGRADATION VS. MILES

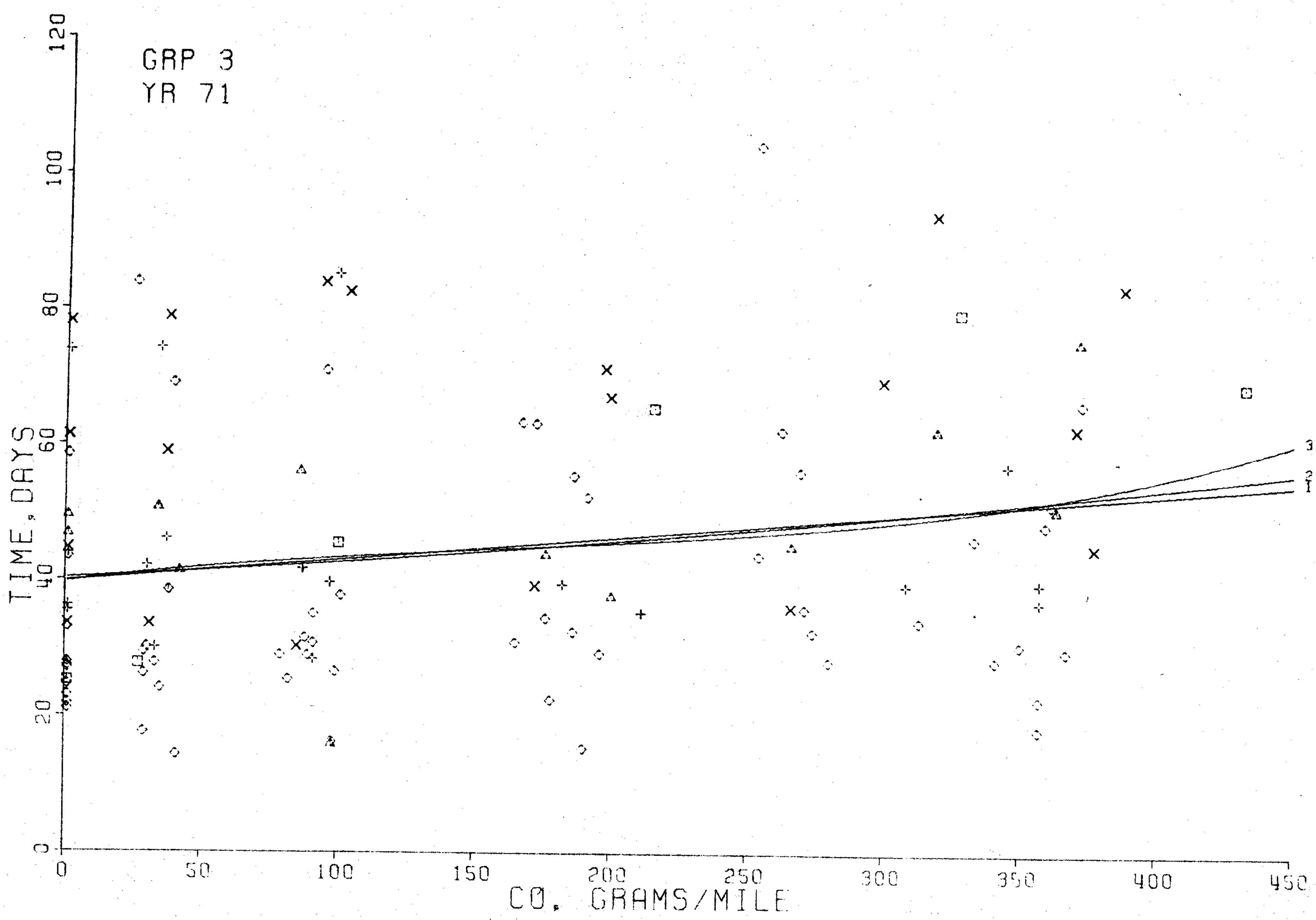


Figure A-63. DEGRADATION VS. TIME

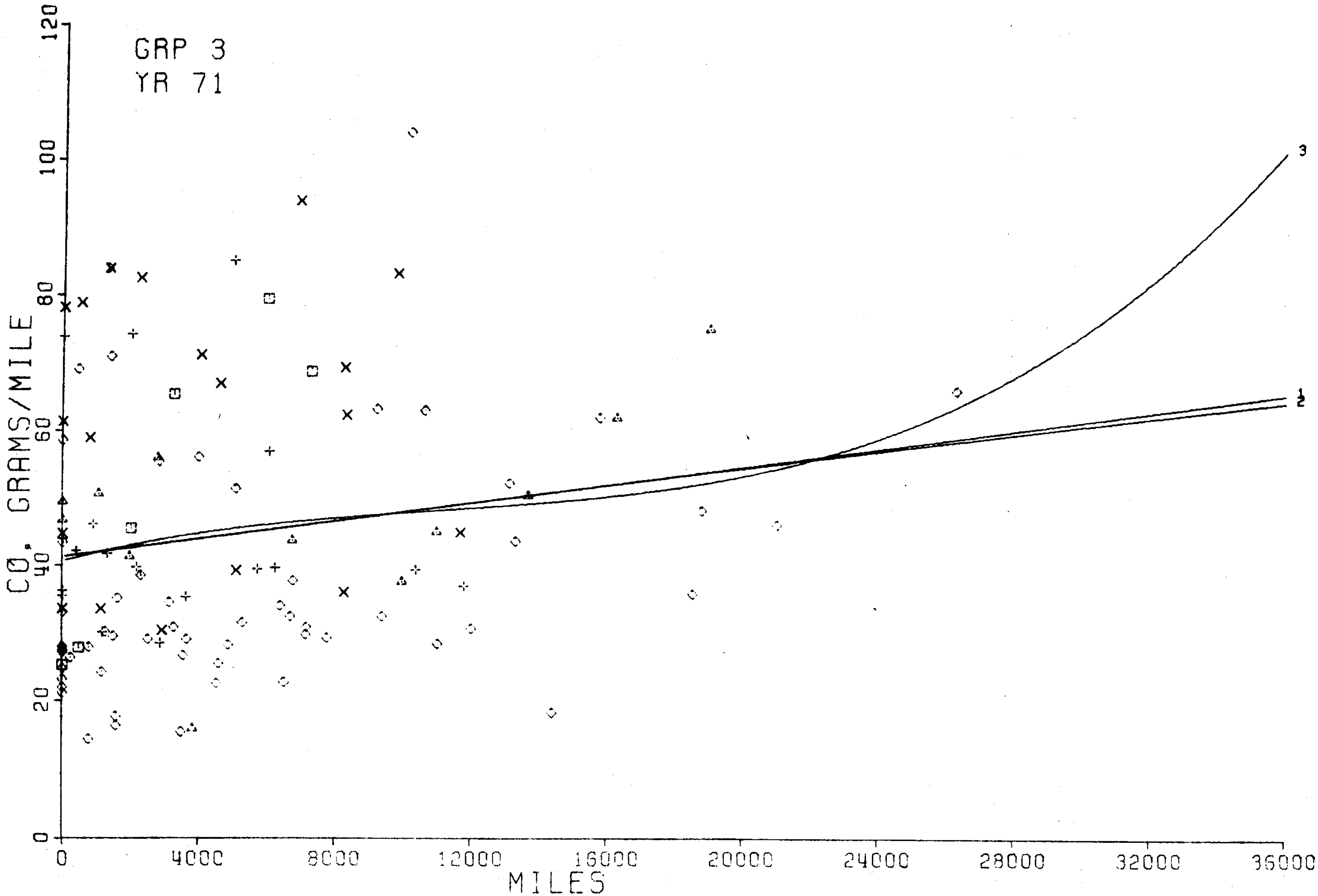


Figure A-64. DEGRADATION VS. MILES

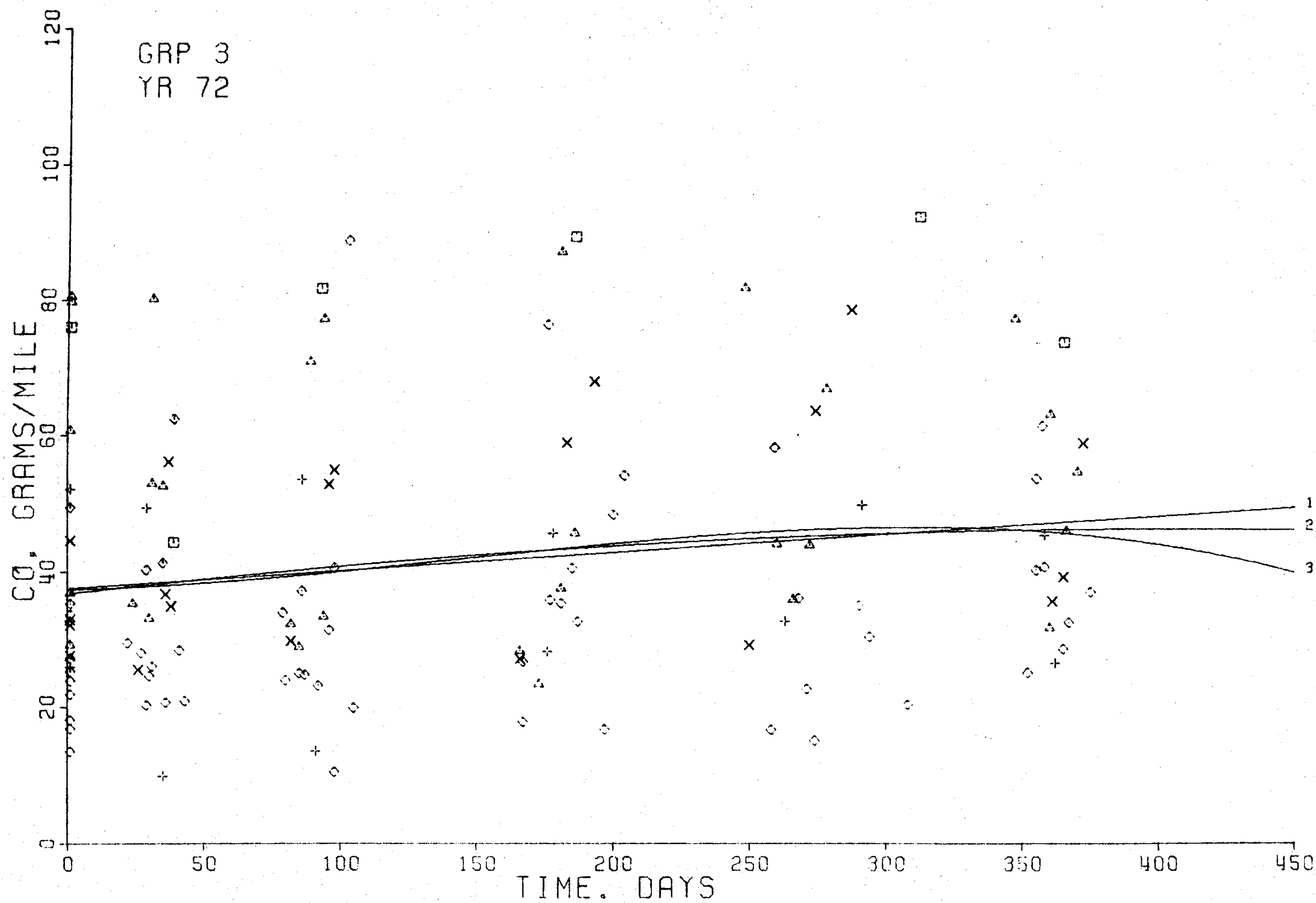


Figure A-65. DEGRADATION VS. TIME

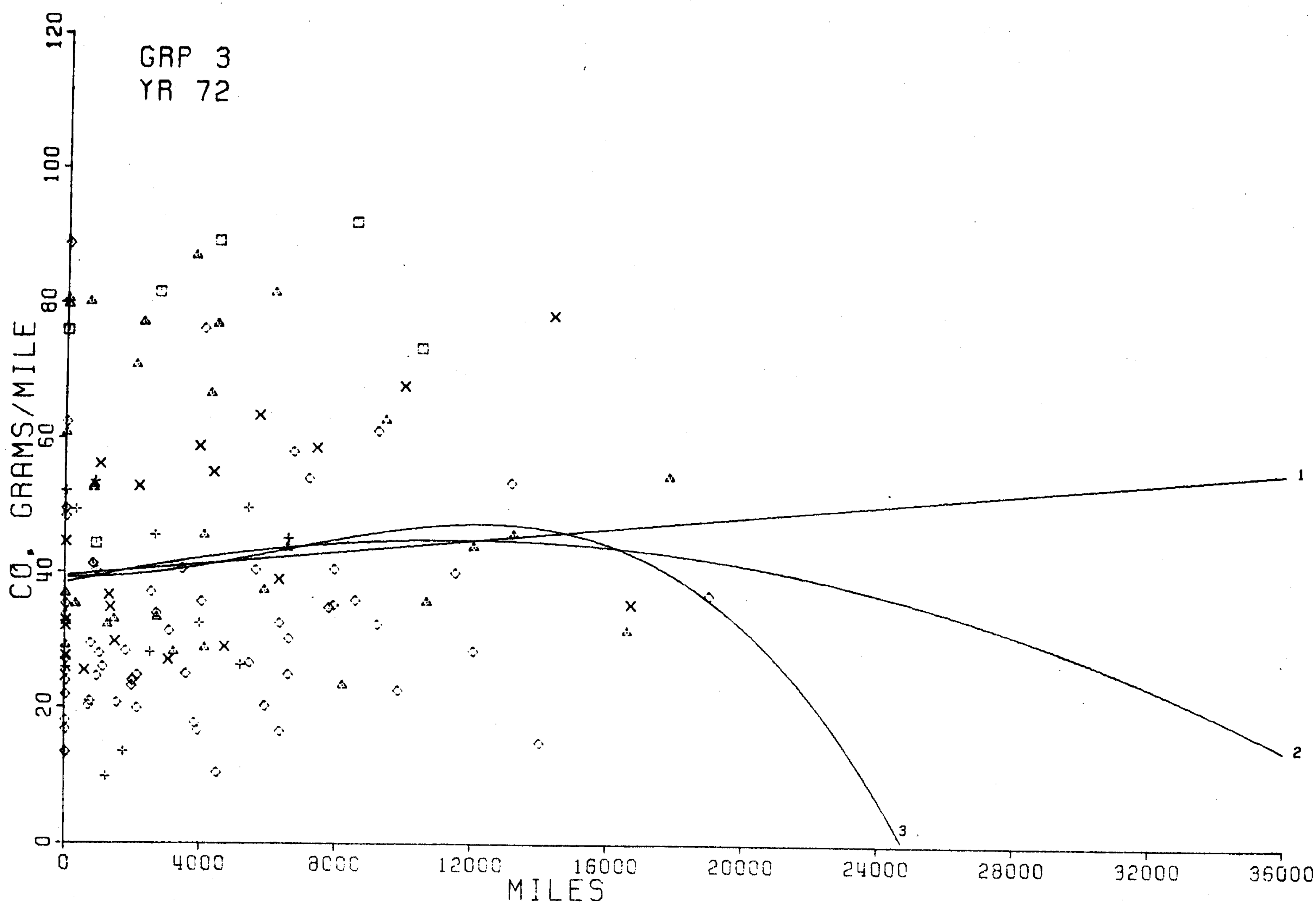


Figure A-66. DEGRADATION VS. MILES

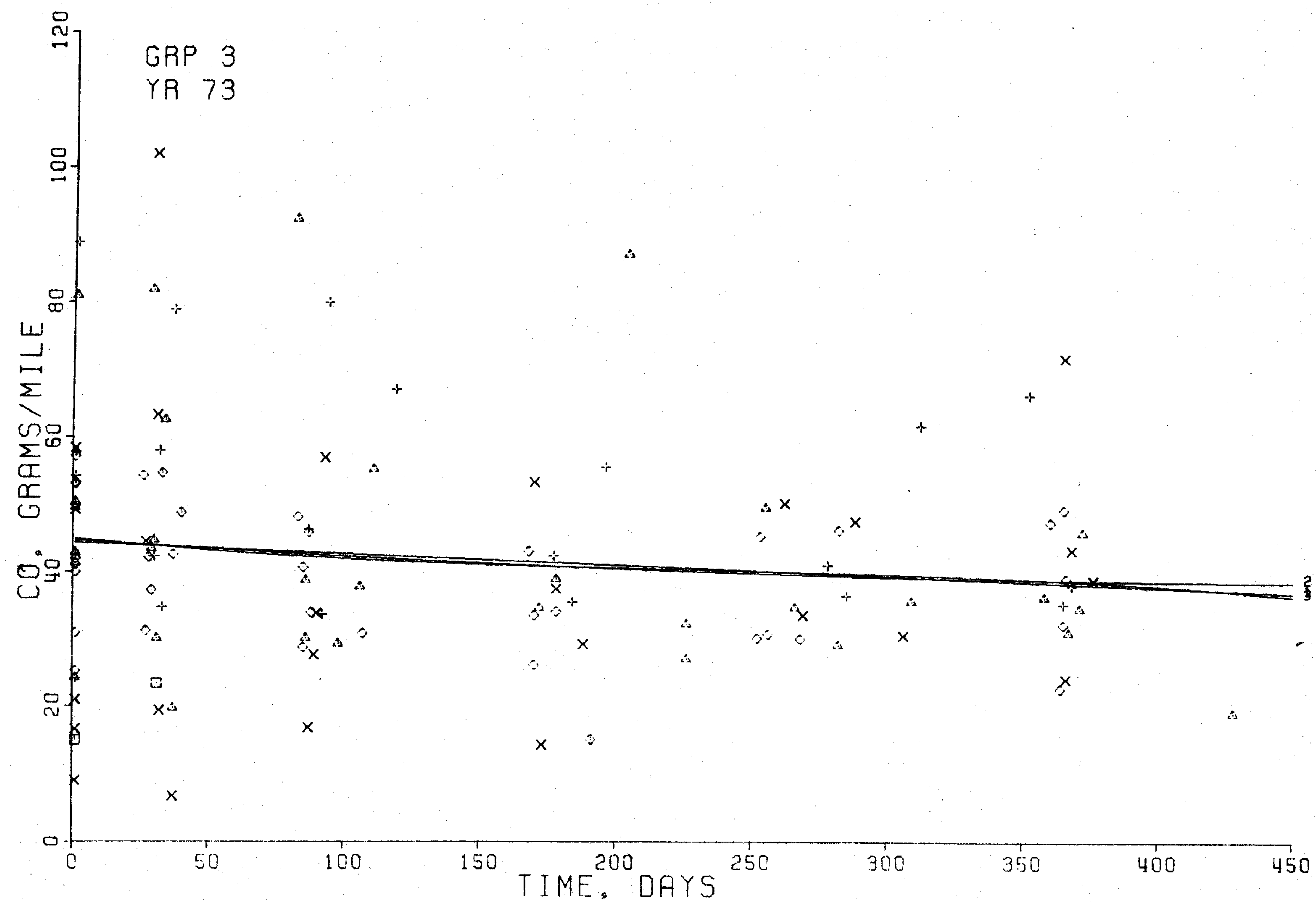


Figure A-67. DEGRADATION VS. TIME

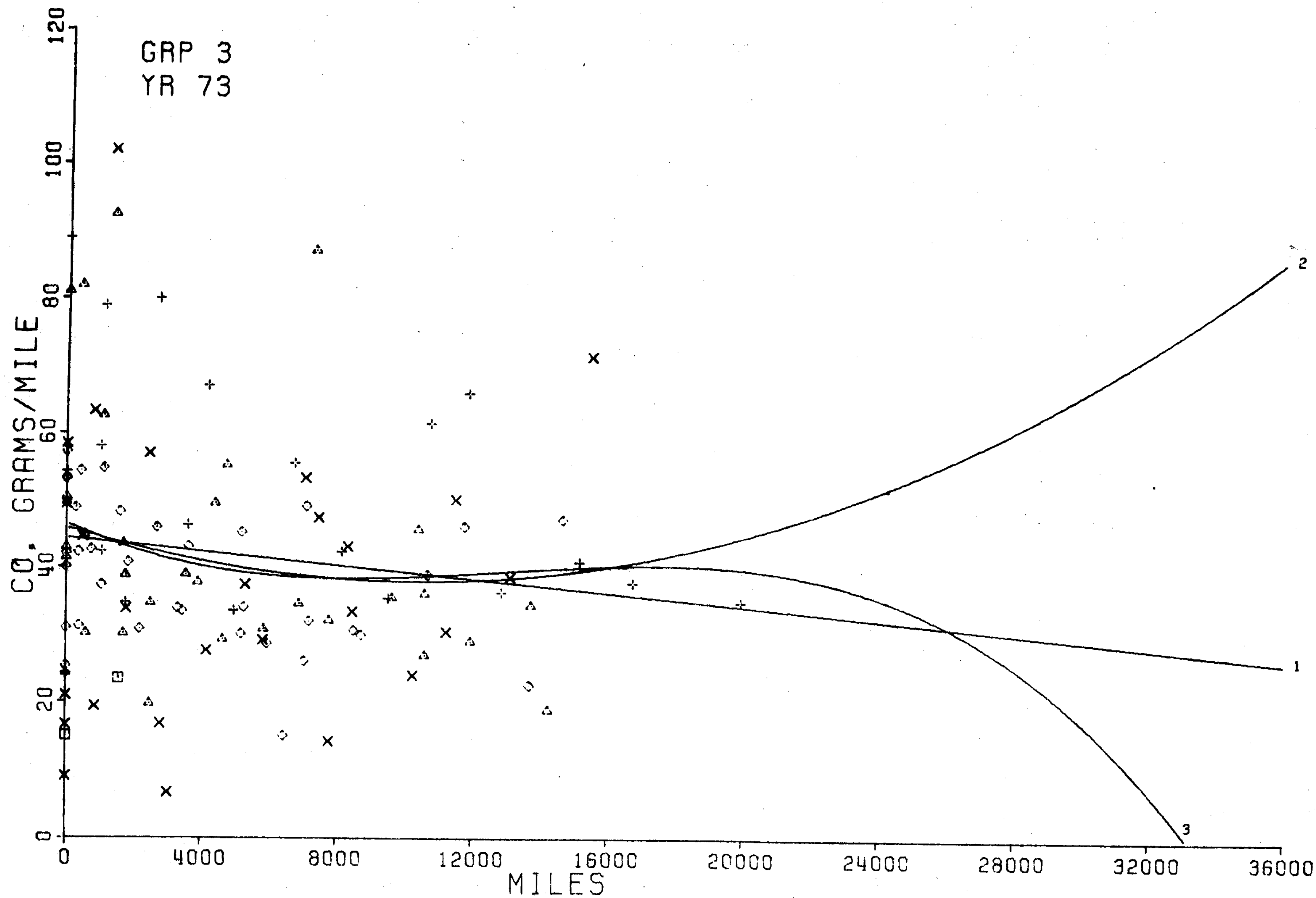


Figure A-68. DEGRADATION VS. MILES

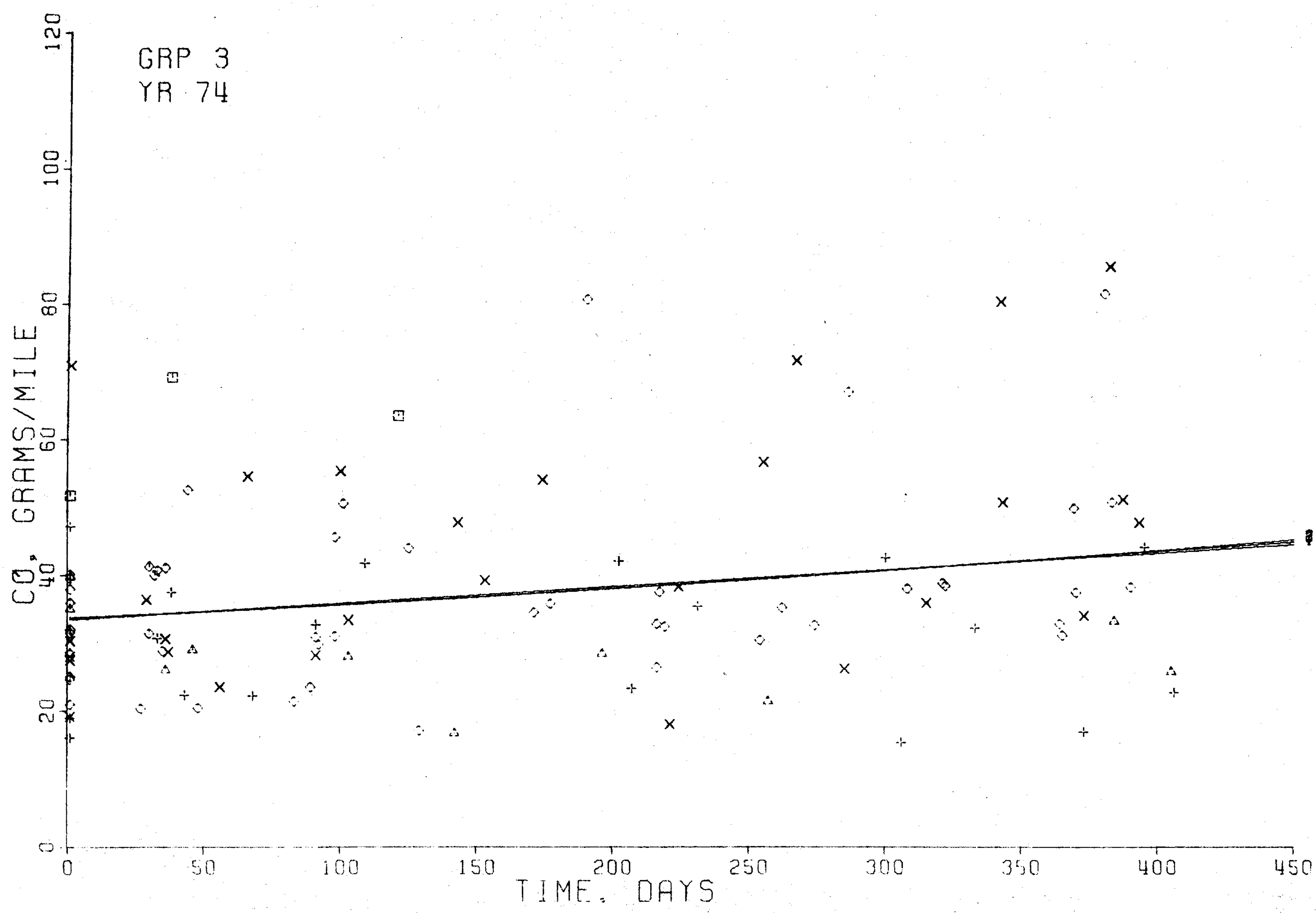


Figure A-69. DEGRADATION VS. TIME

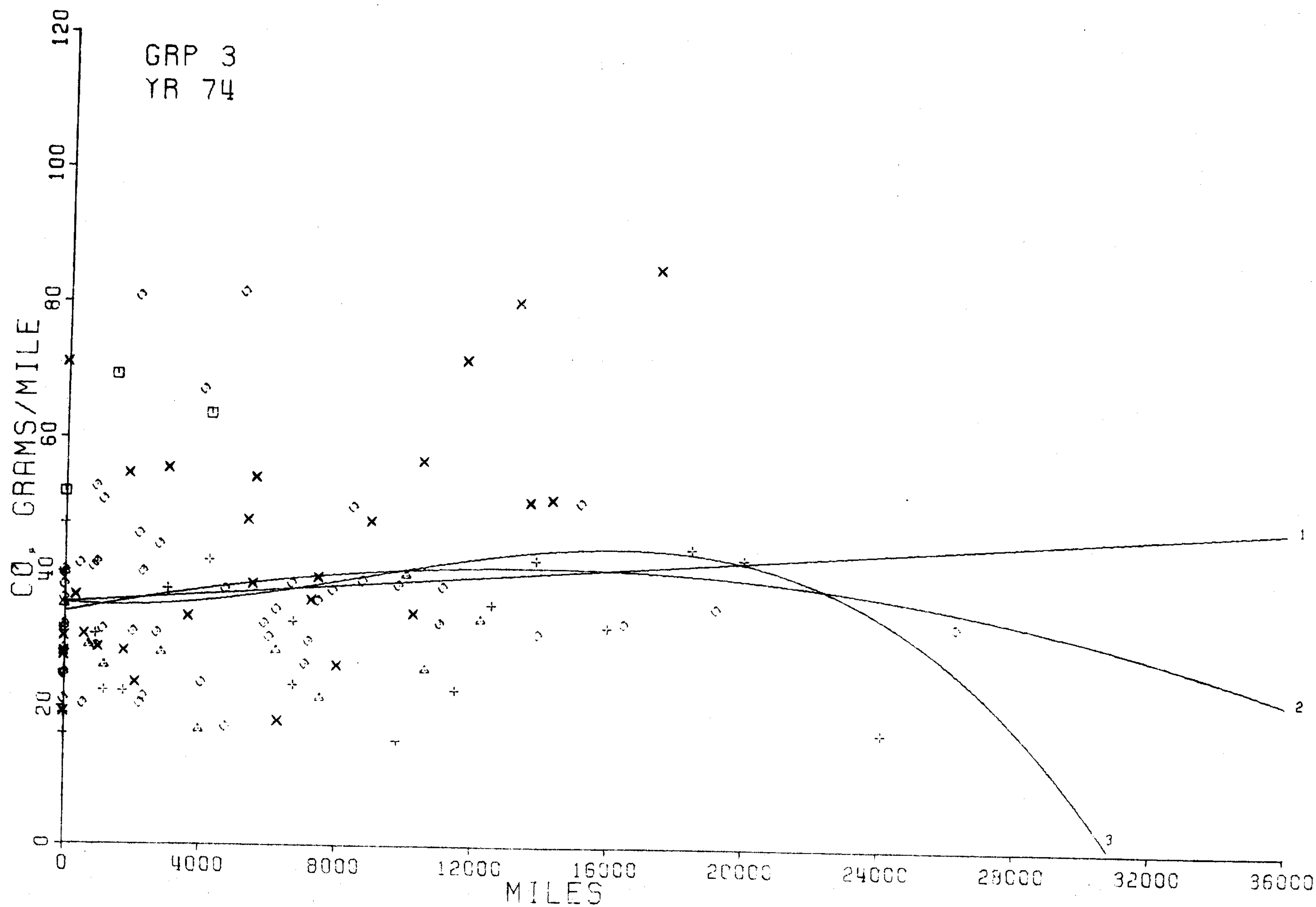


Figure A-70. DEGRADATION VS. MILES

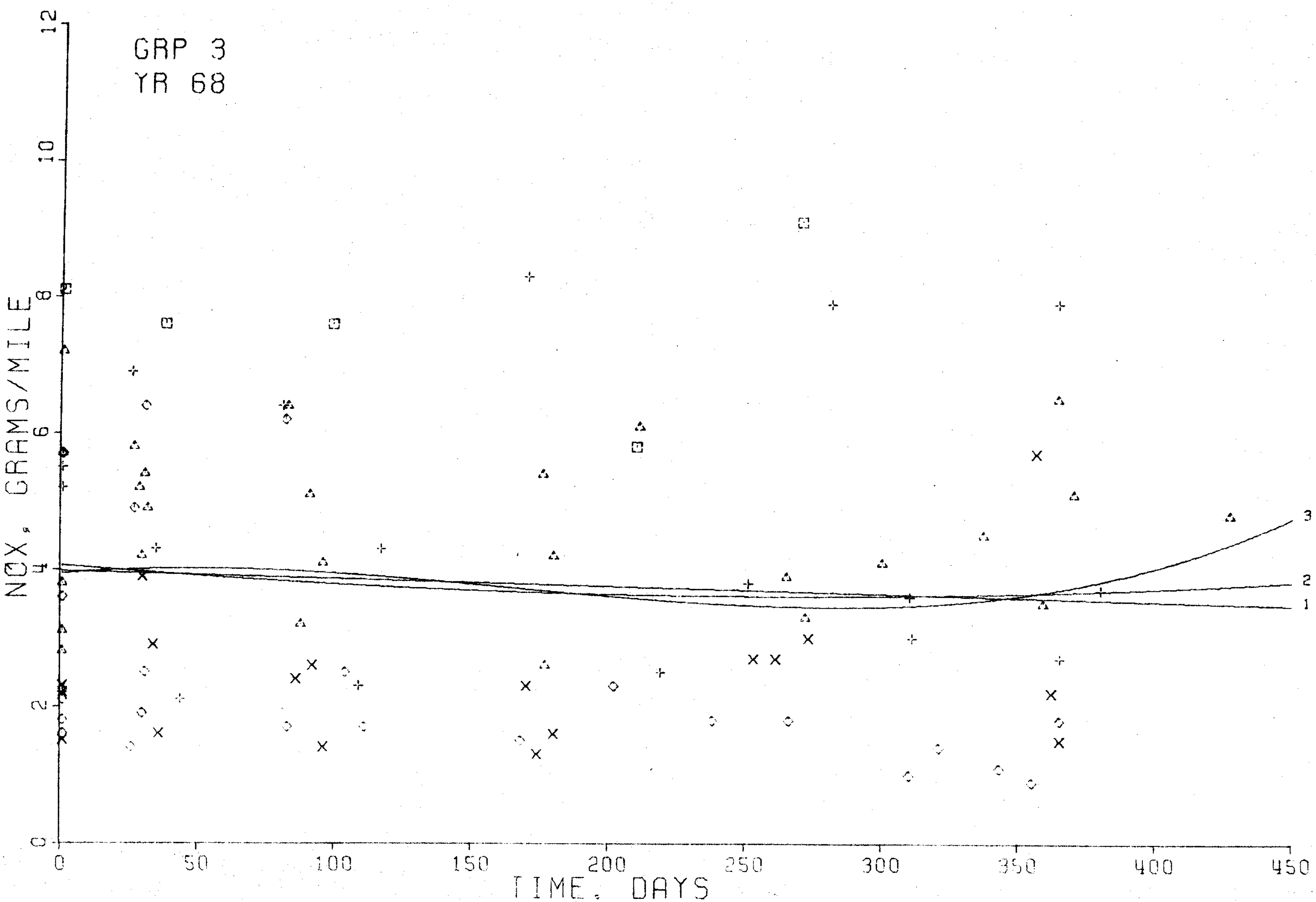


Figure A-71. DEGRADATION VS. TIME

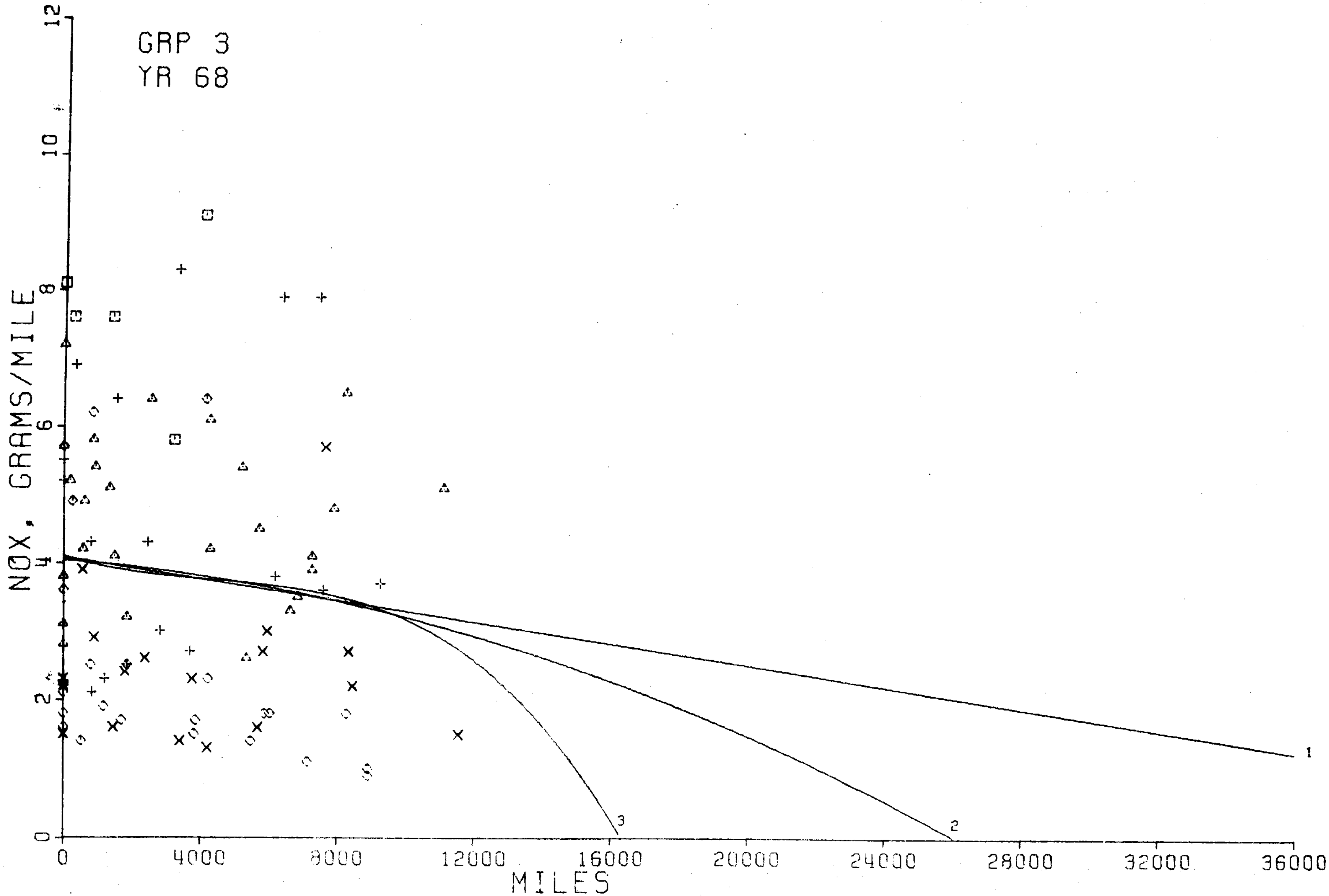


Figure A-72. DEGRADATION VS. MILES

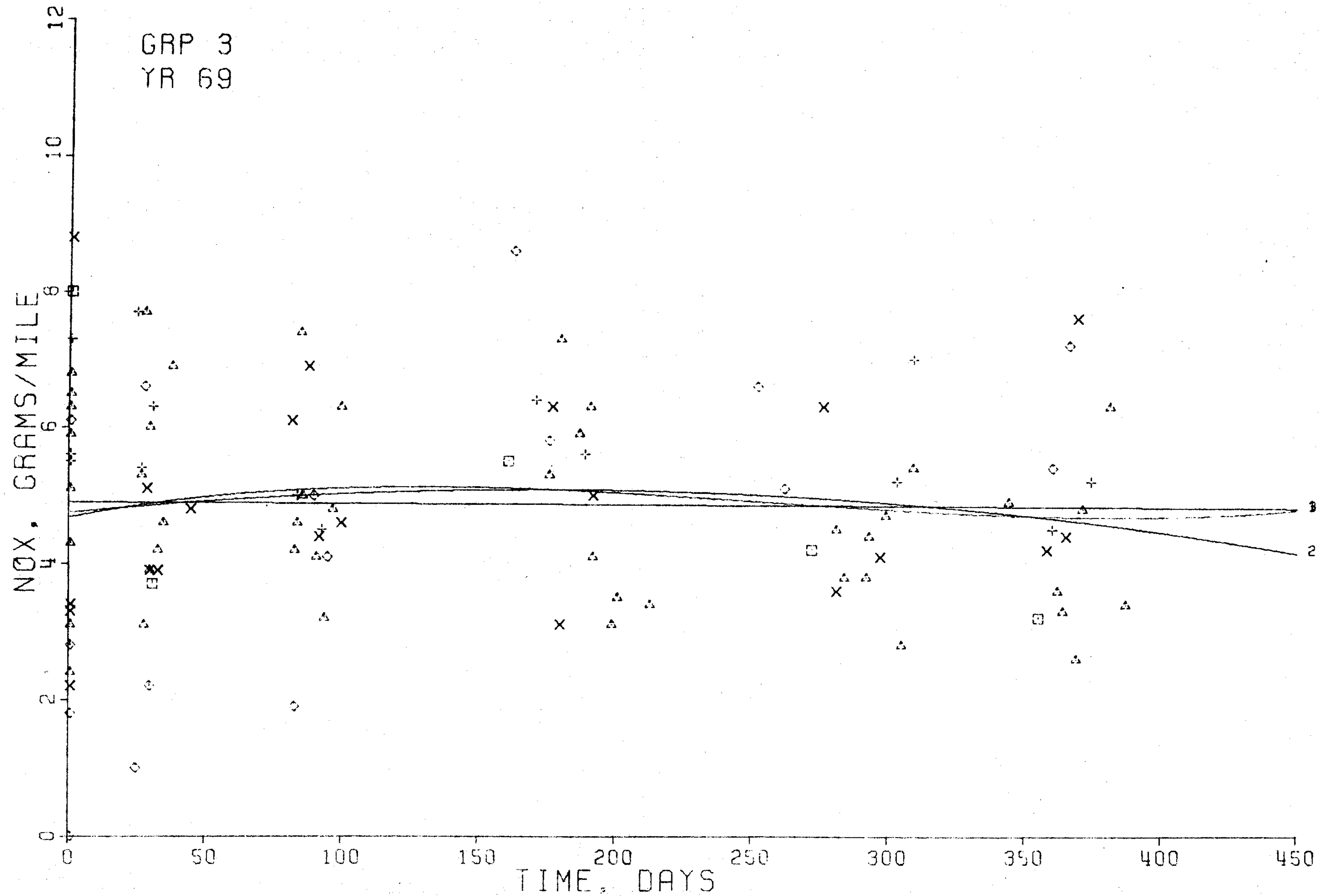


Figure A-73. DEGRADATION VS. TIME

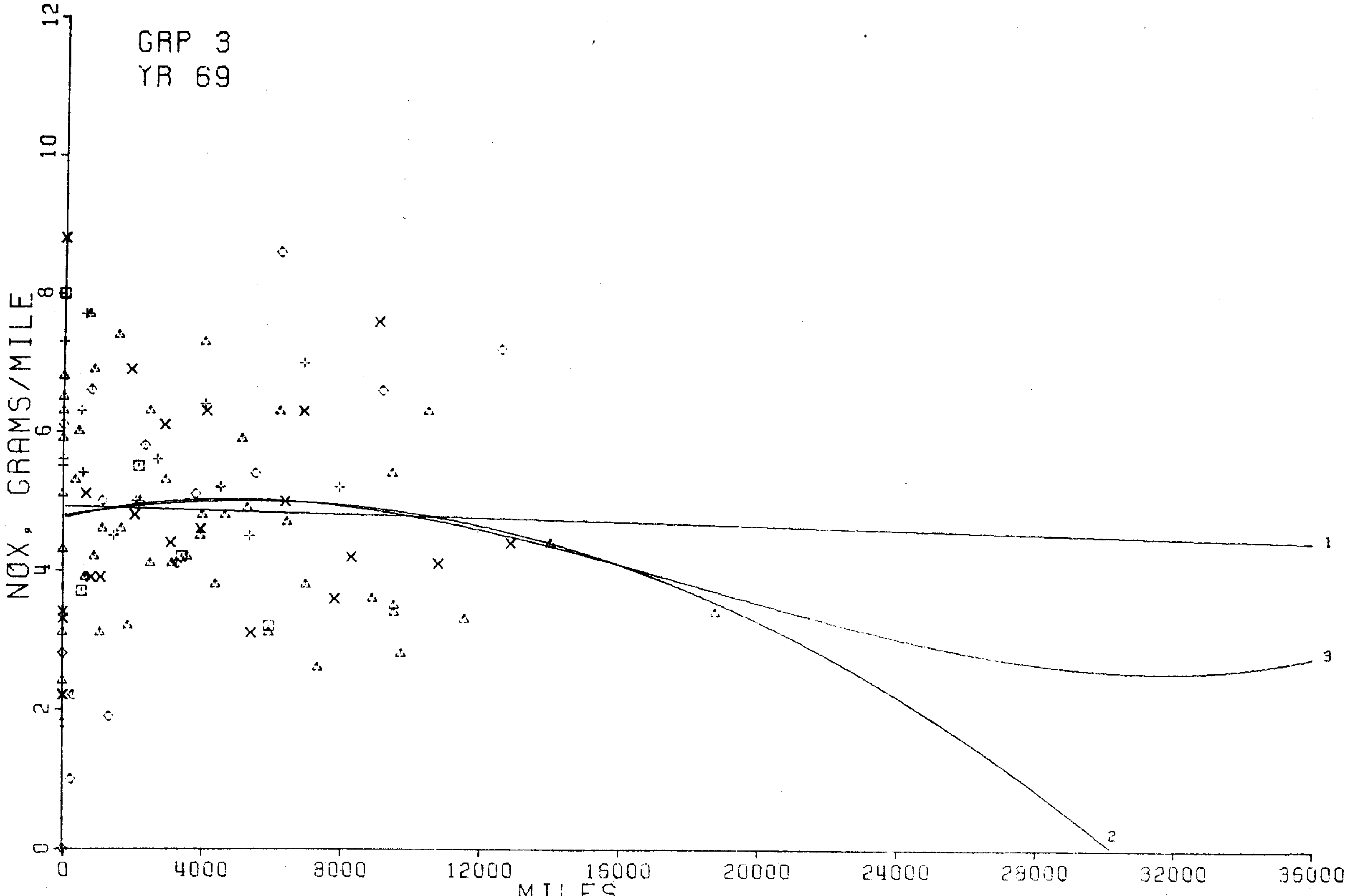


Figure A-74. DEGRADATION VS. MILES

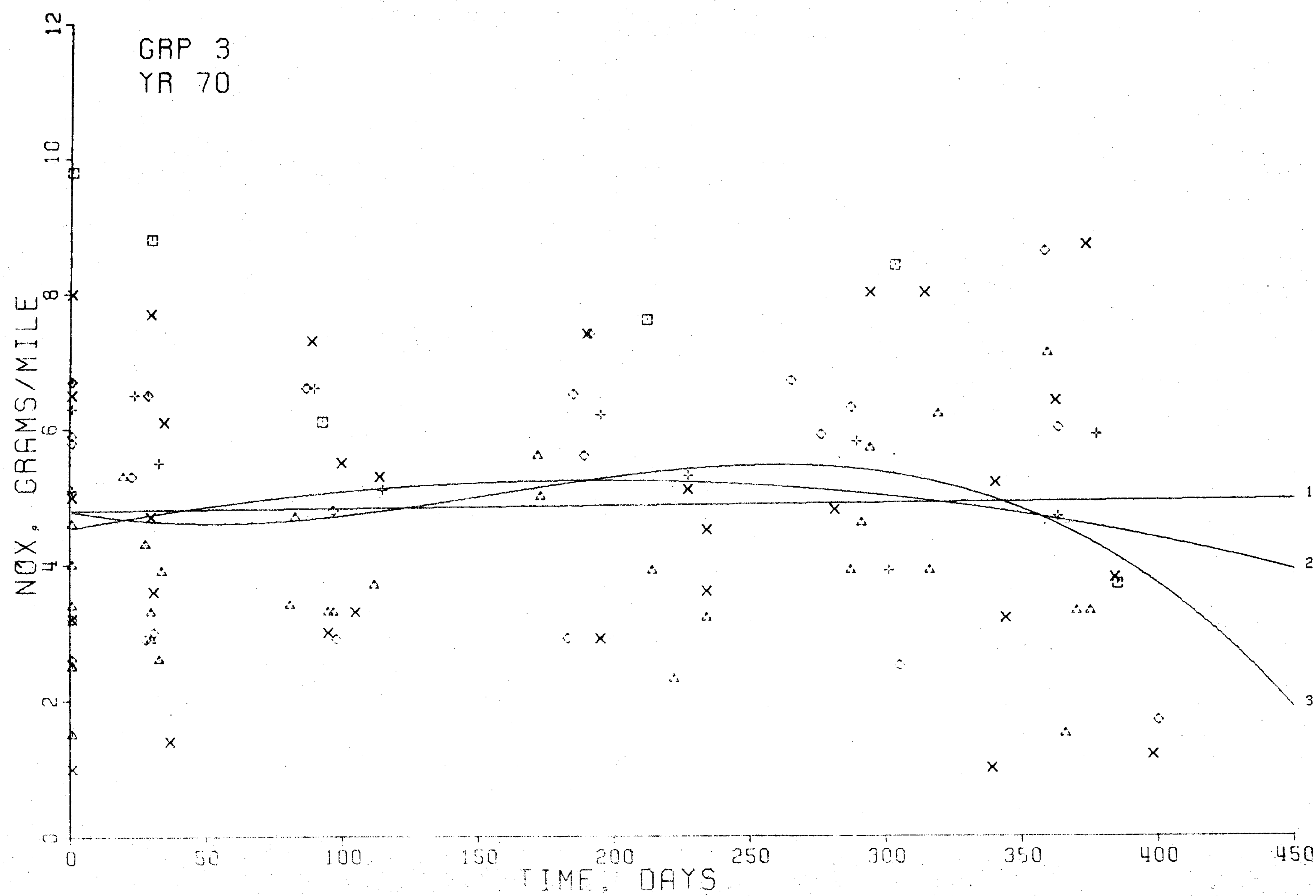


Figure A-75. DEGRADATION VS. TIME

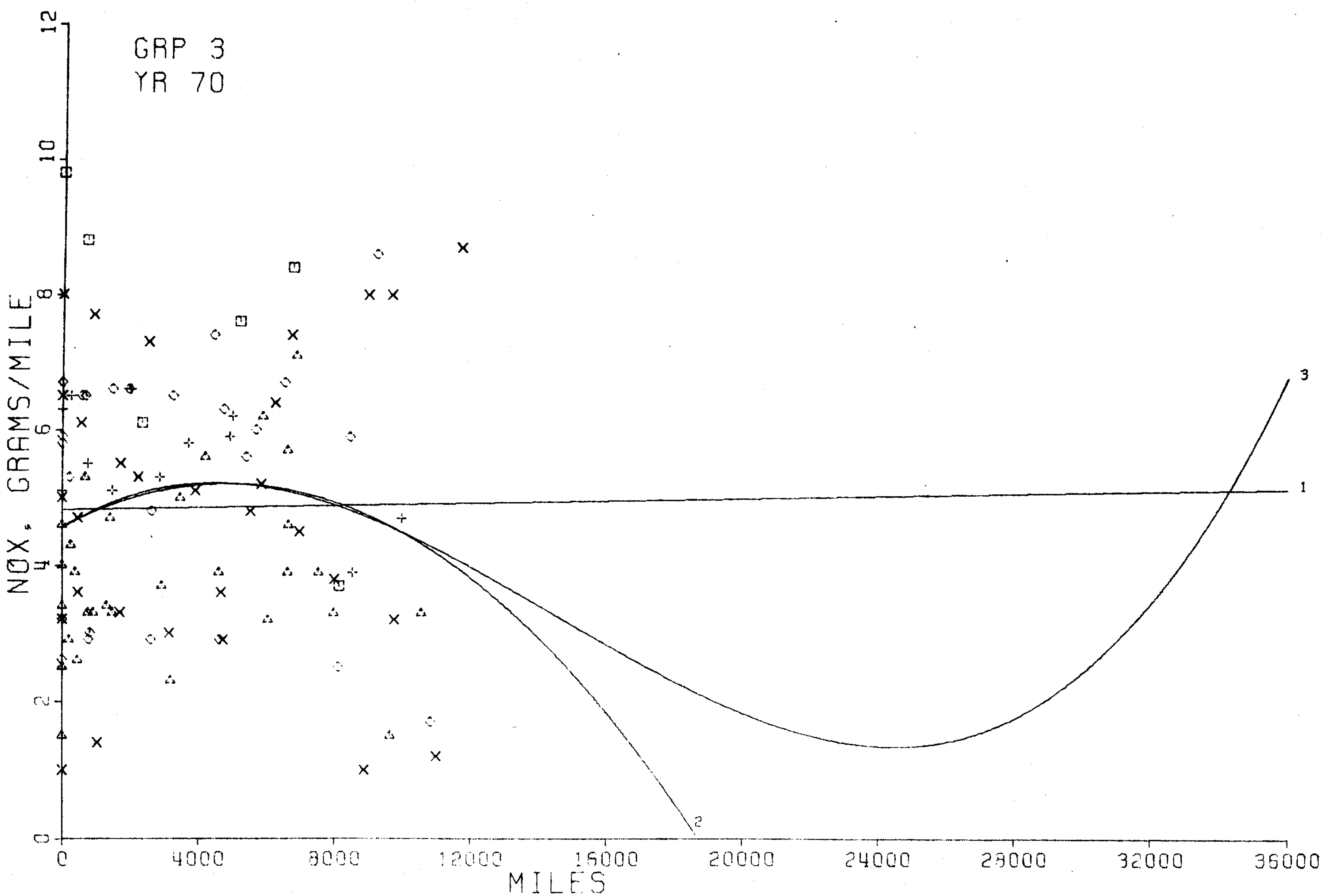


Figure A-76. DEGRADATION VS. MILES

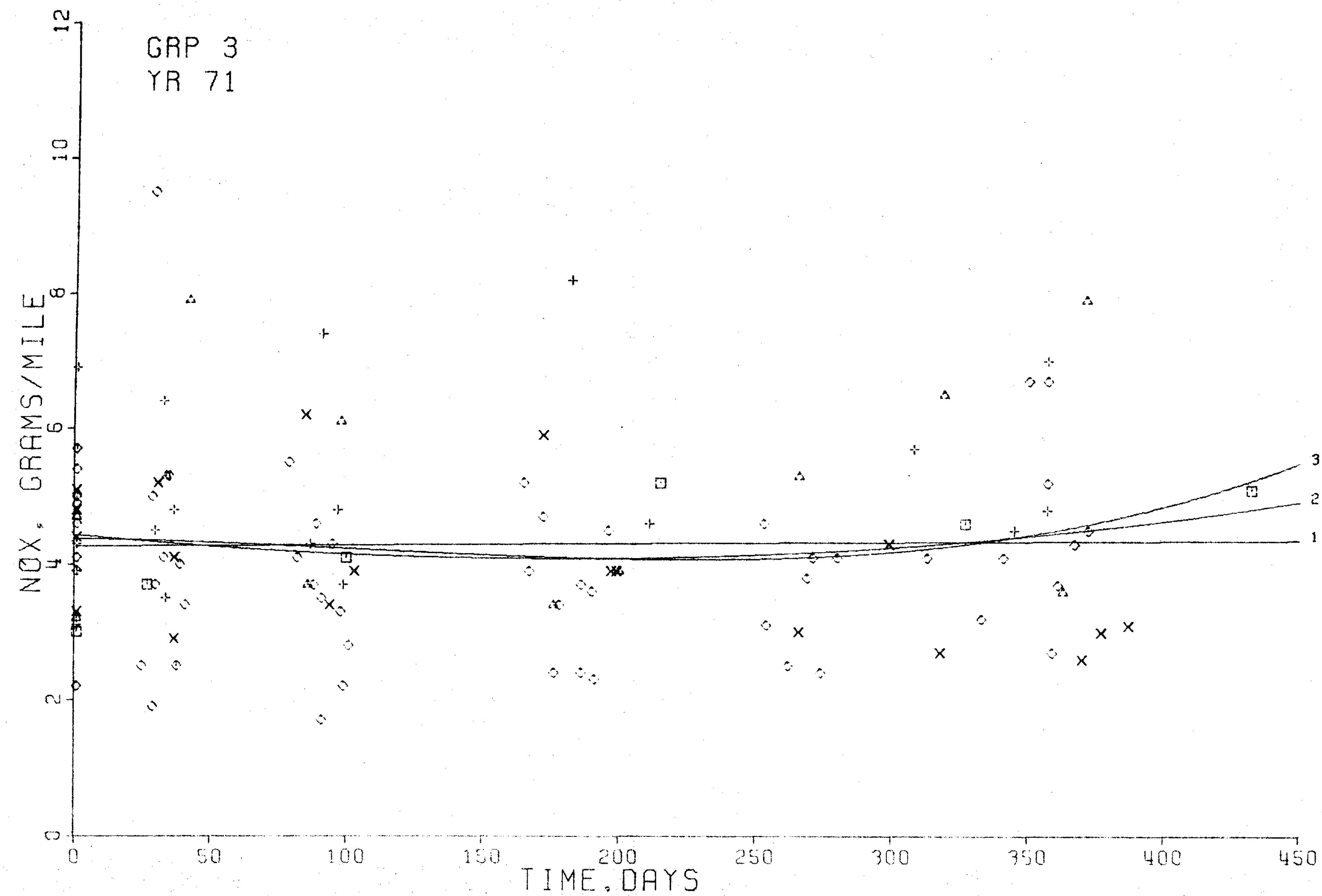


Figure A-77. DEGRADATION VS. TIME

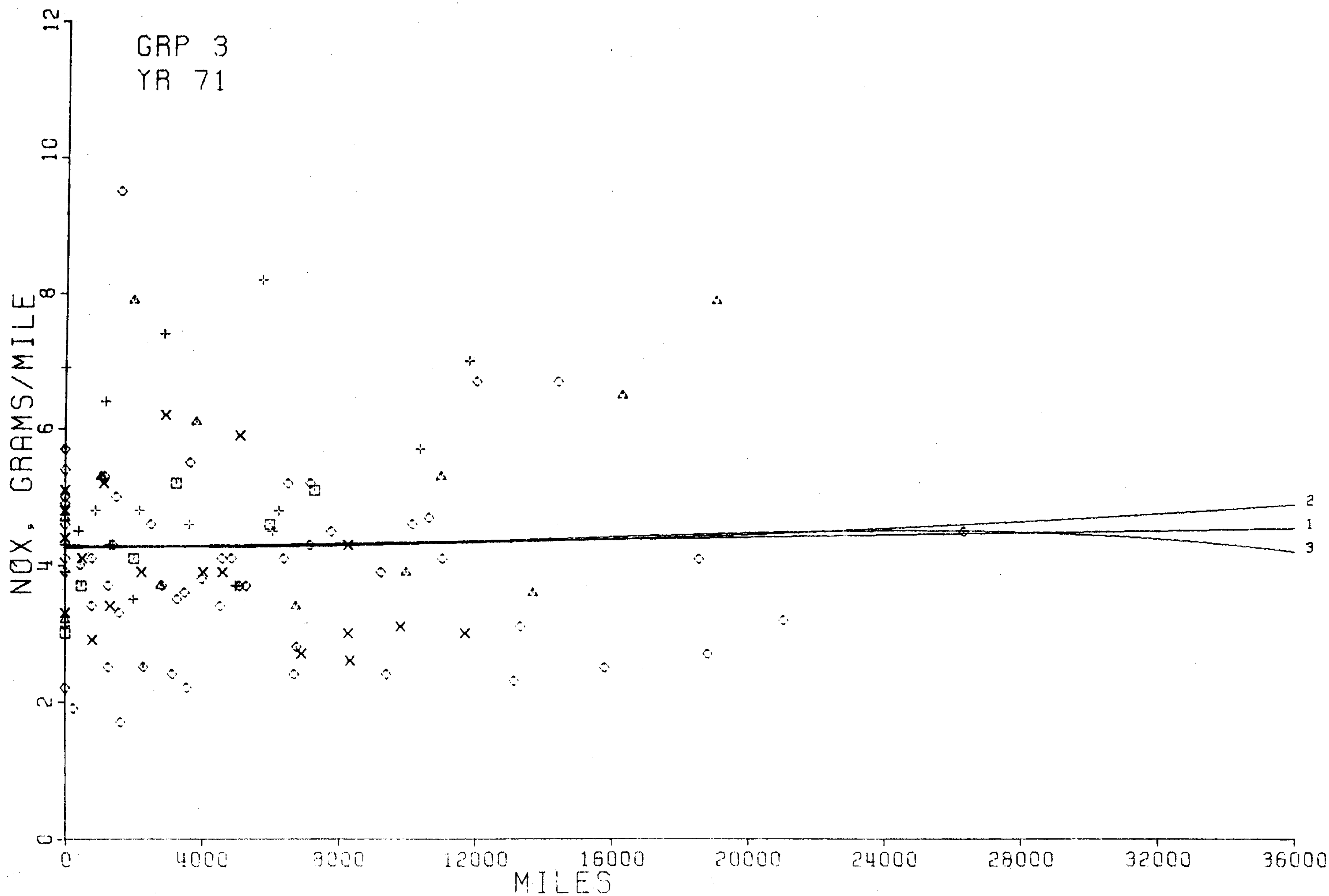


Figure A-78. DEGRADATION VS. MILES

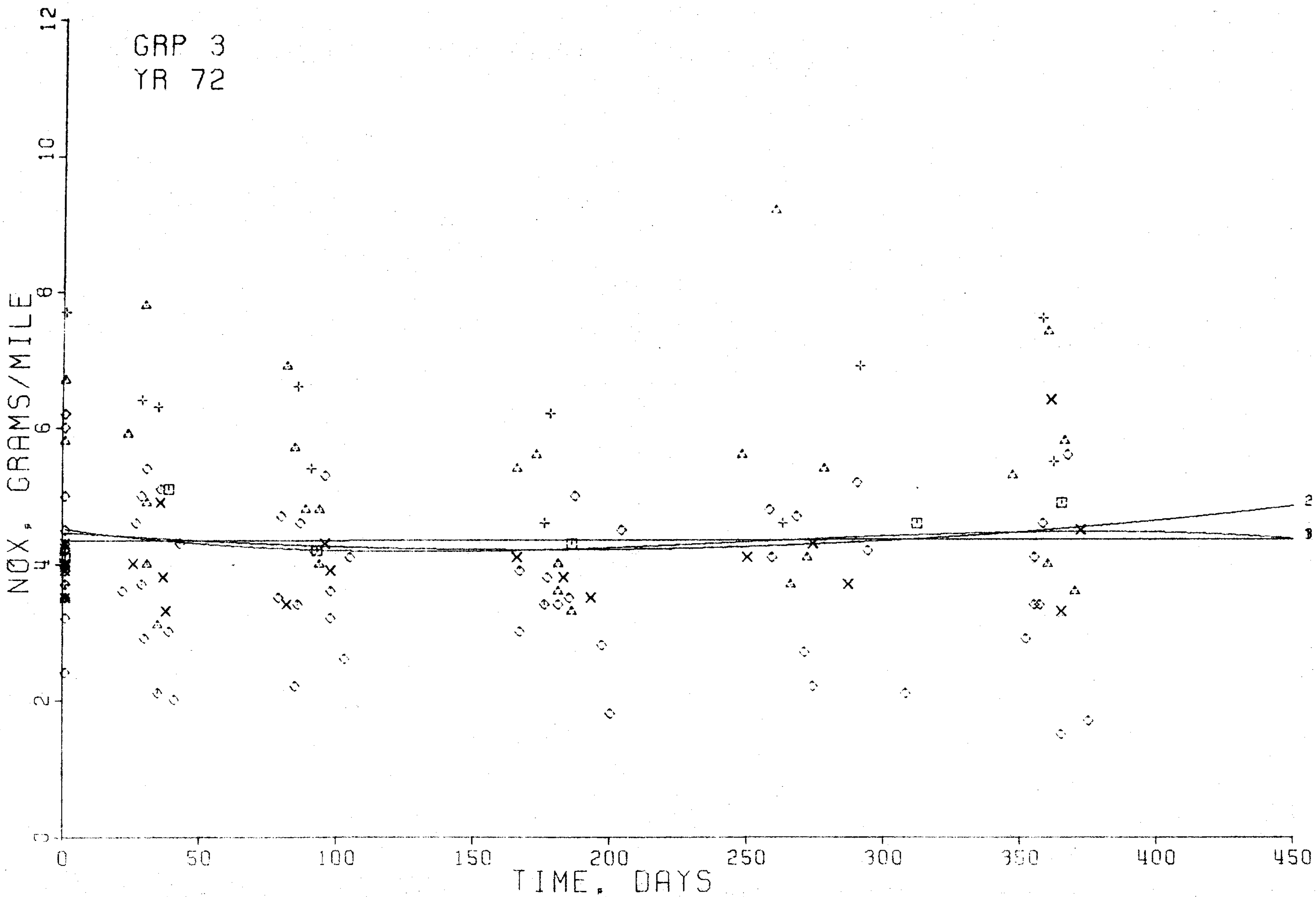


Figure A-79. DEGRADATION VS. TIME

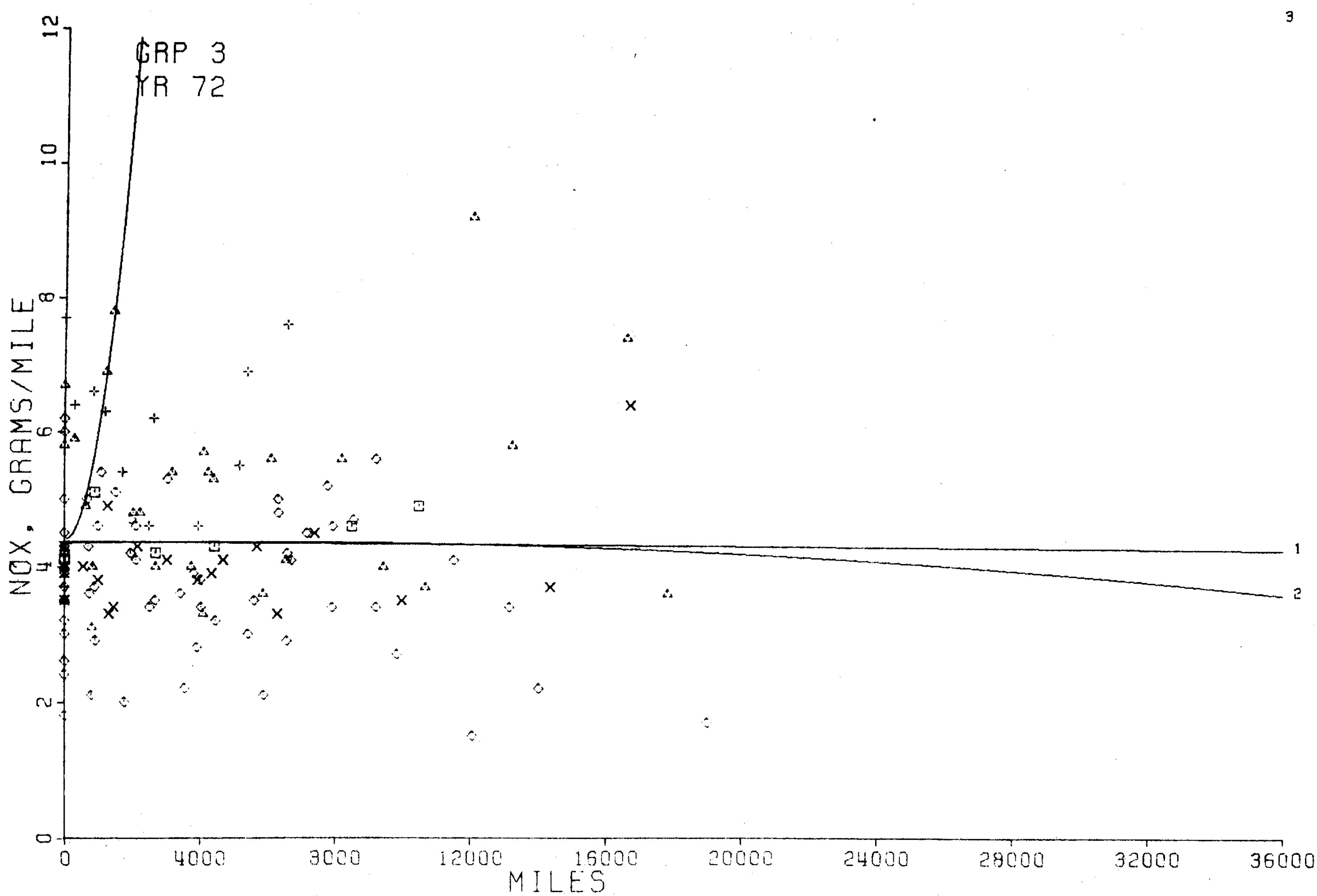


Figure A-80. DEGRADATION VS. MILES

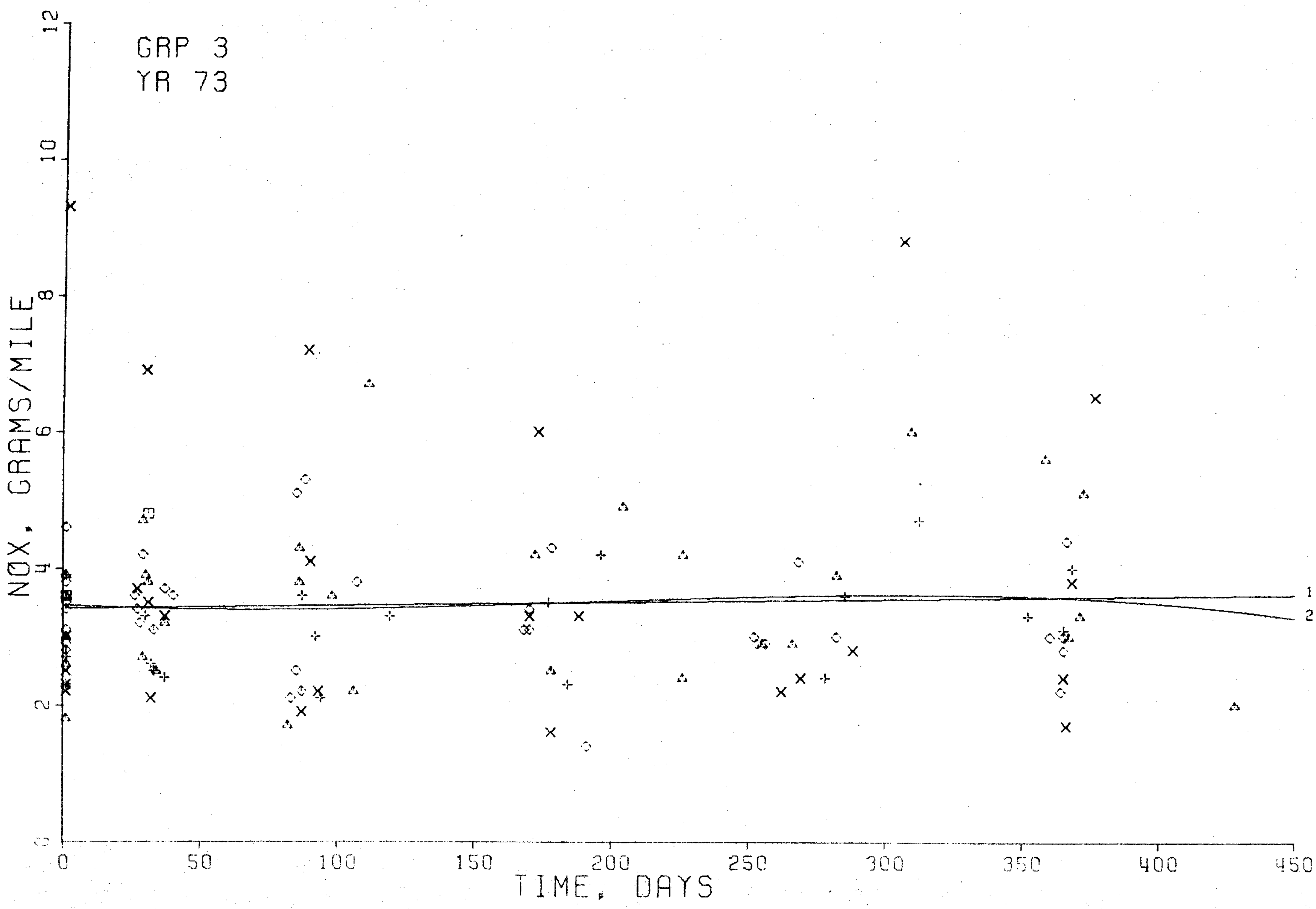


Figure A-81. DEGRADATION VS. TIME

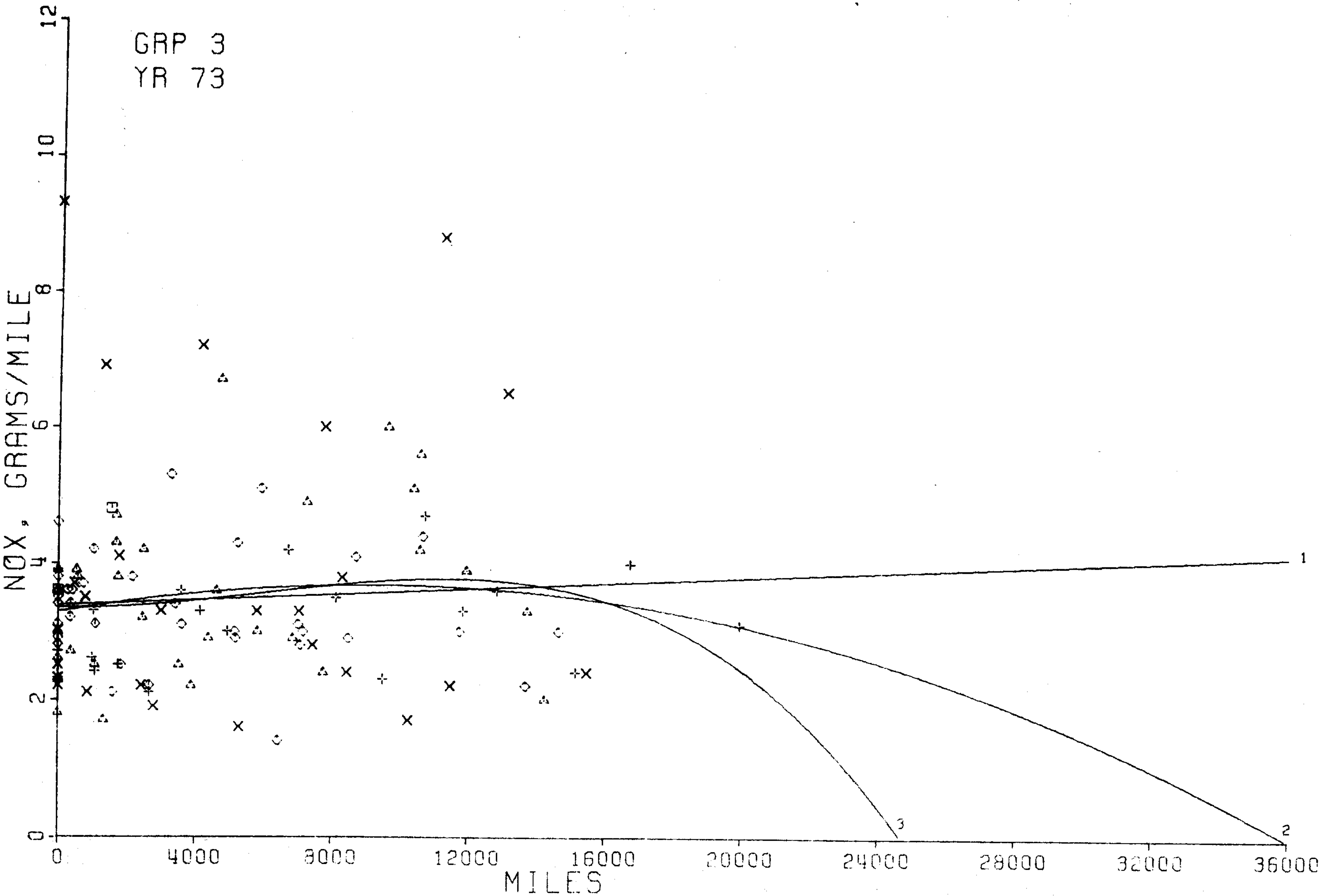


Figure A-82. DEGRADATION VS. MILES

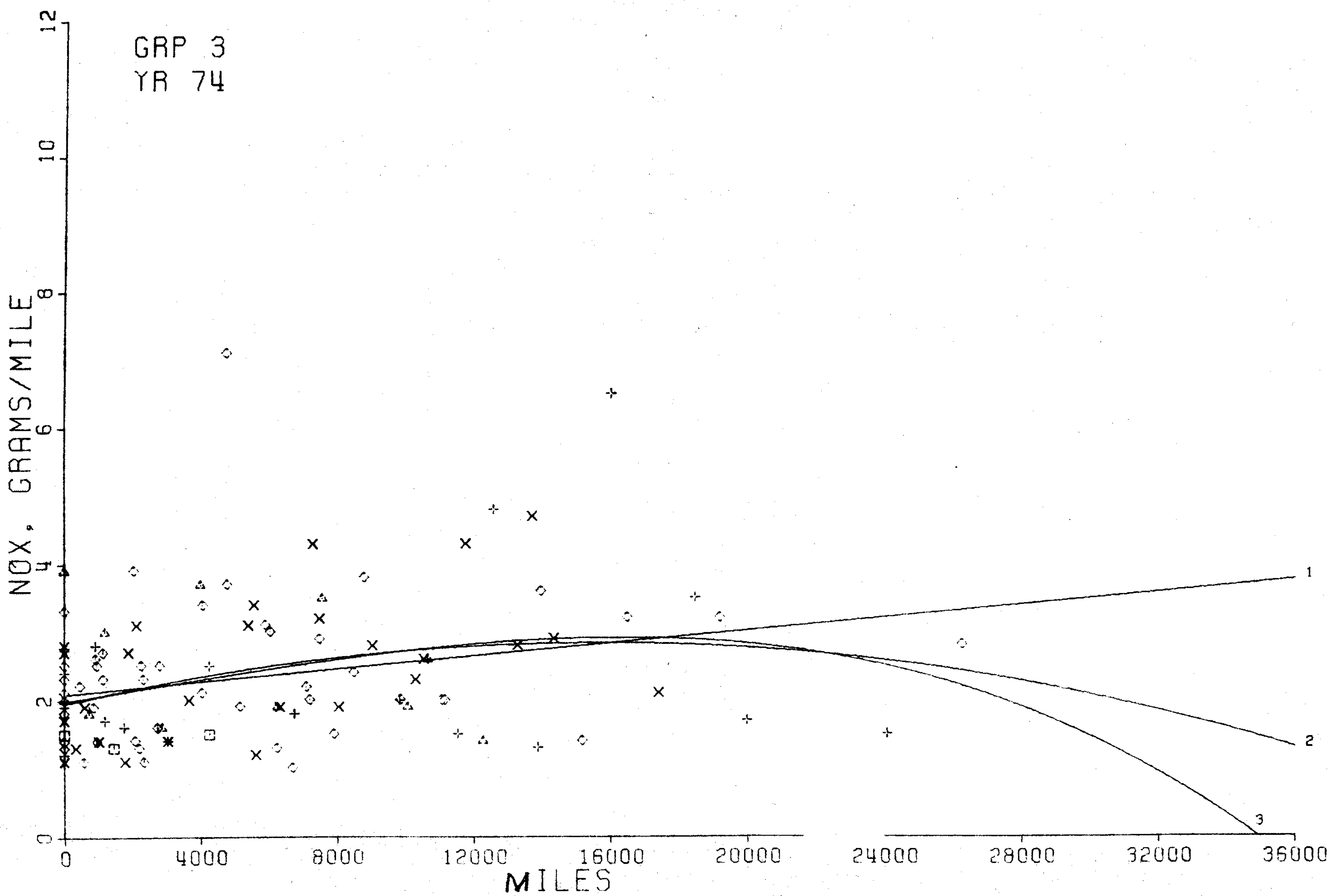


Figure A-84. DEGRADATION VS. MILES

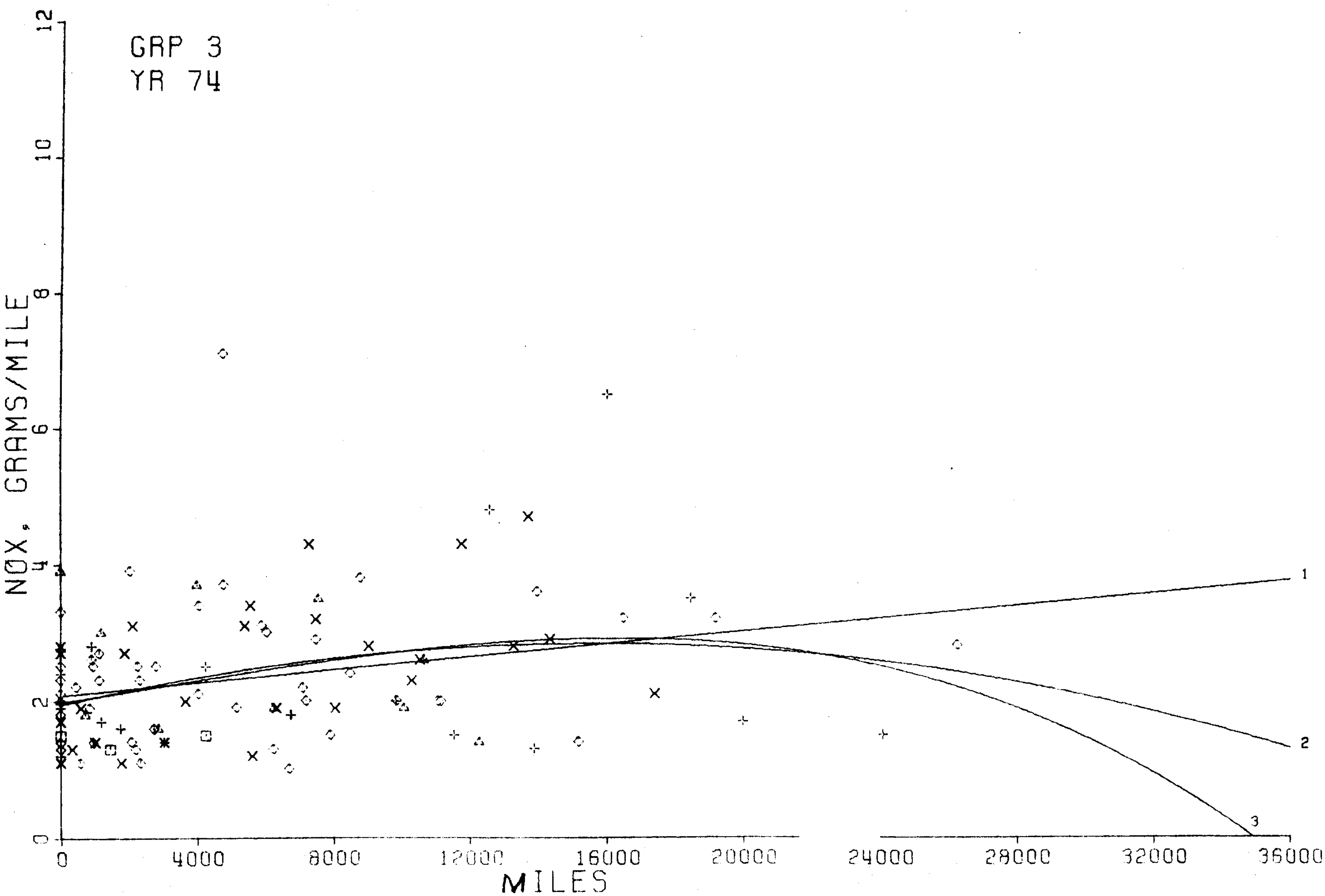


Figure A-84. DEGRADATION VS. MILES

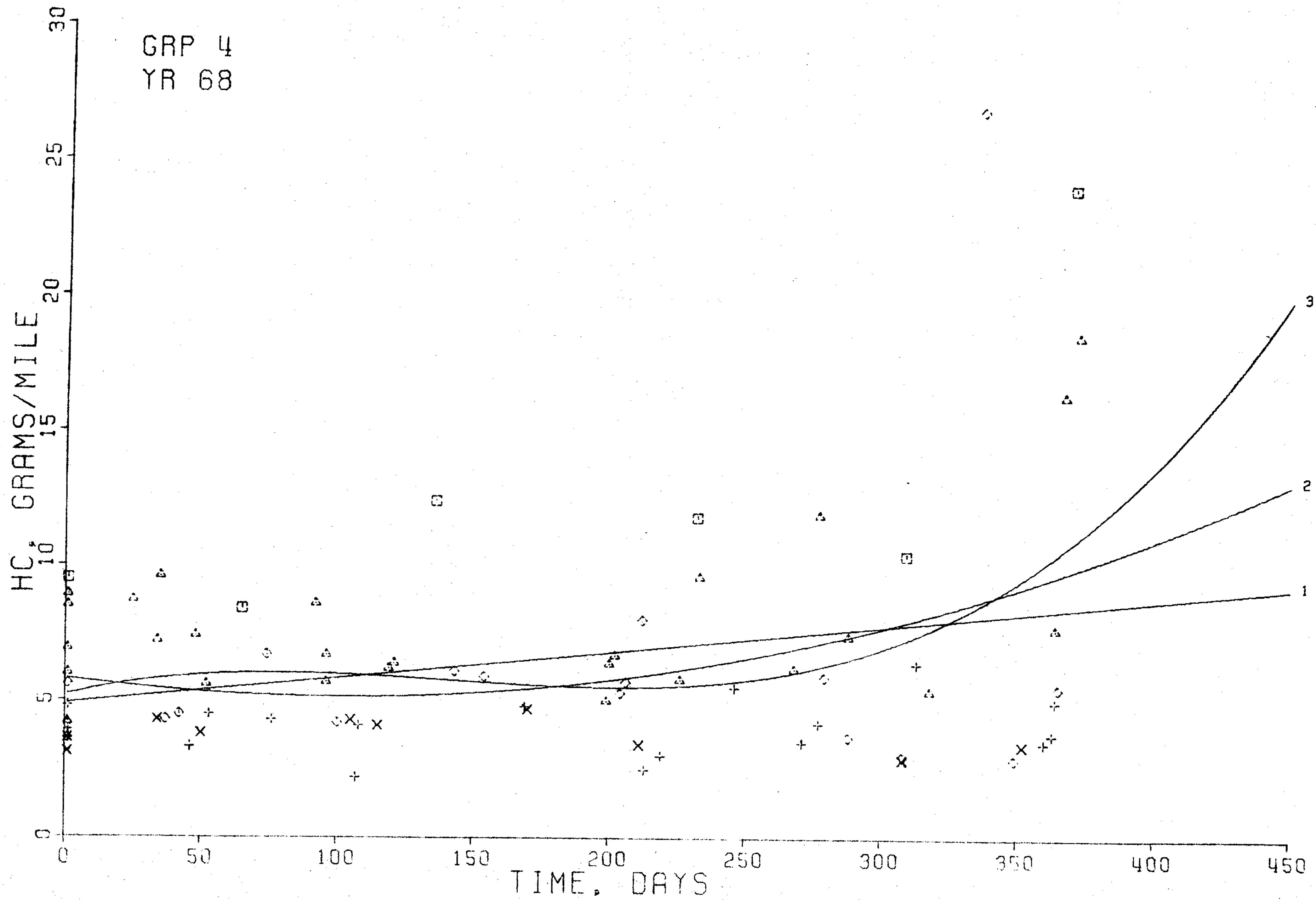


Figure A-85. DEGRADATION VS. TIME

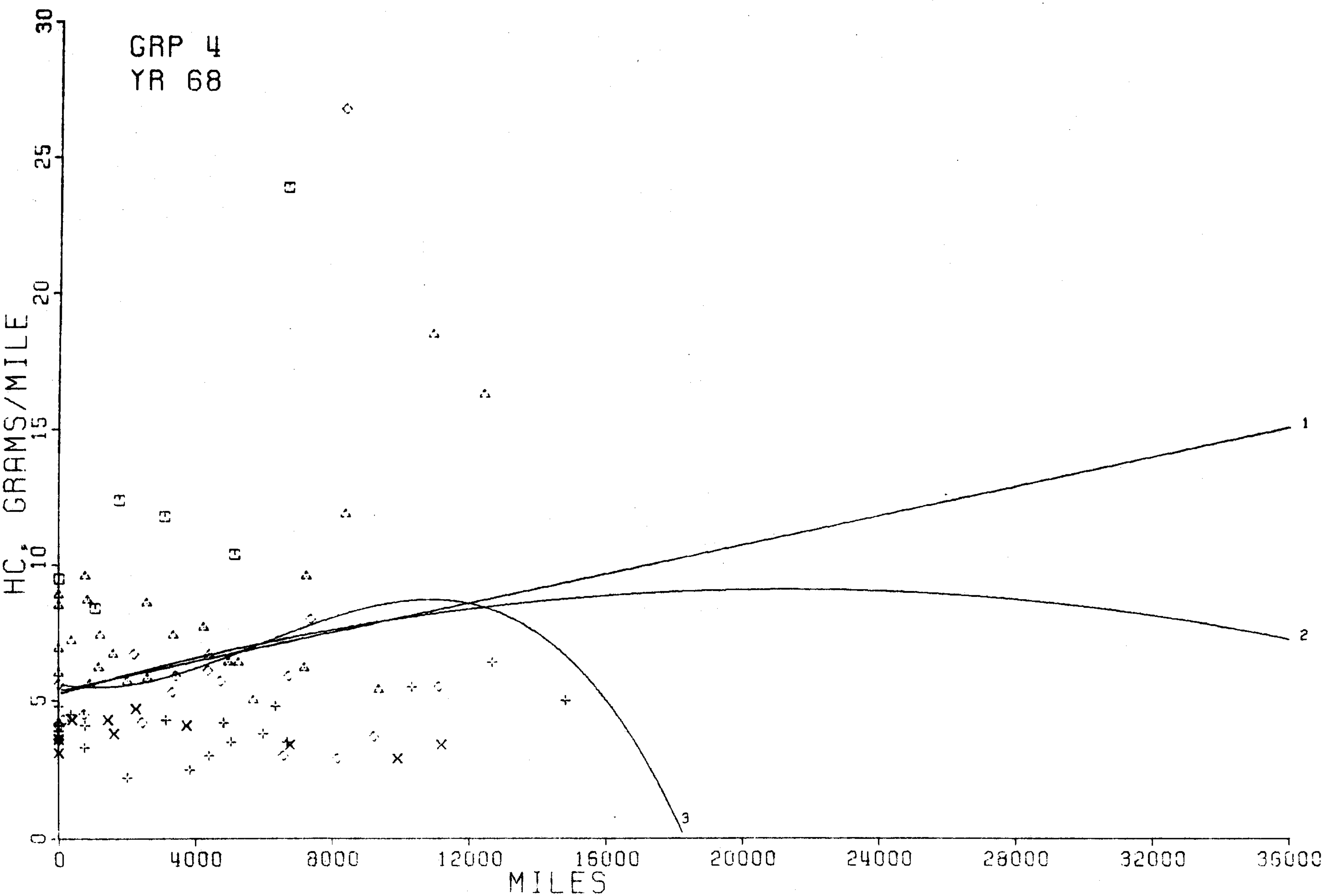


Figure A-86. DEGRADATION VS. MILES

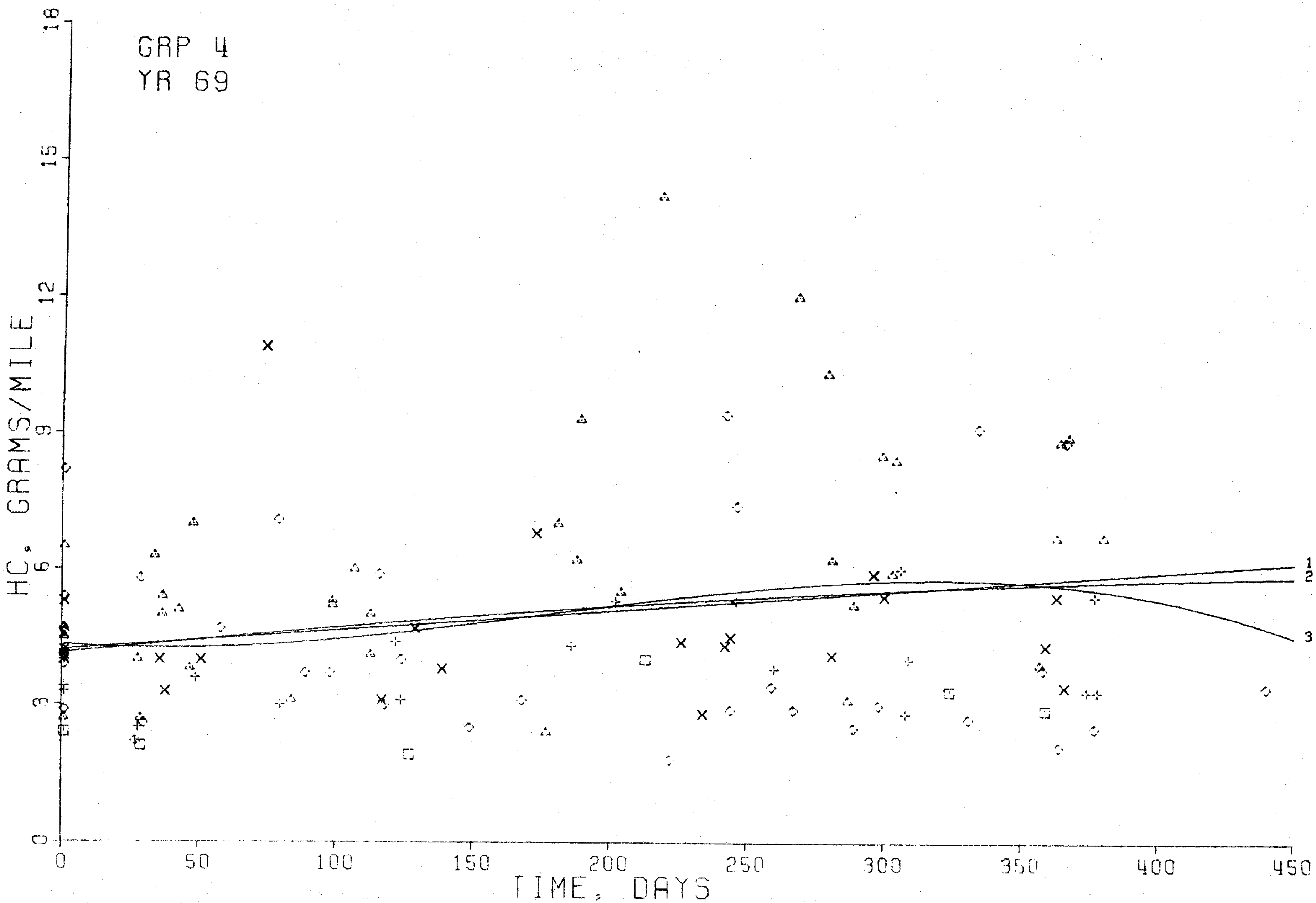


Figure A-87. DEGRADATION VS. TIME

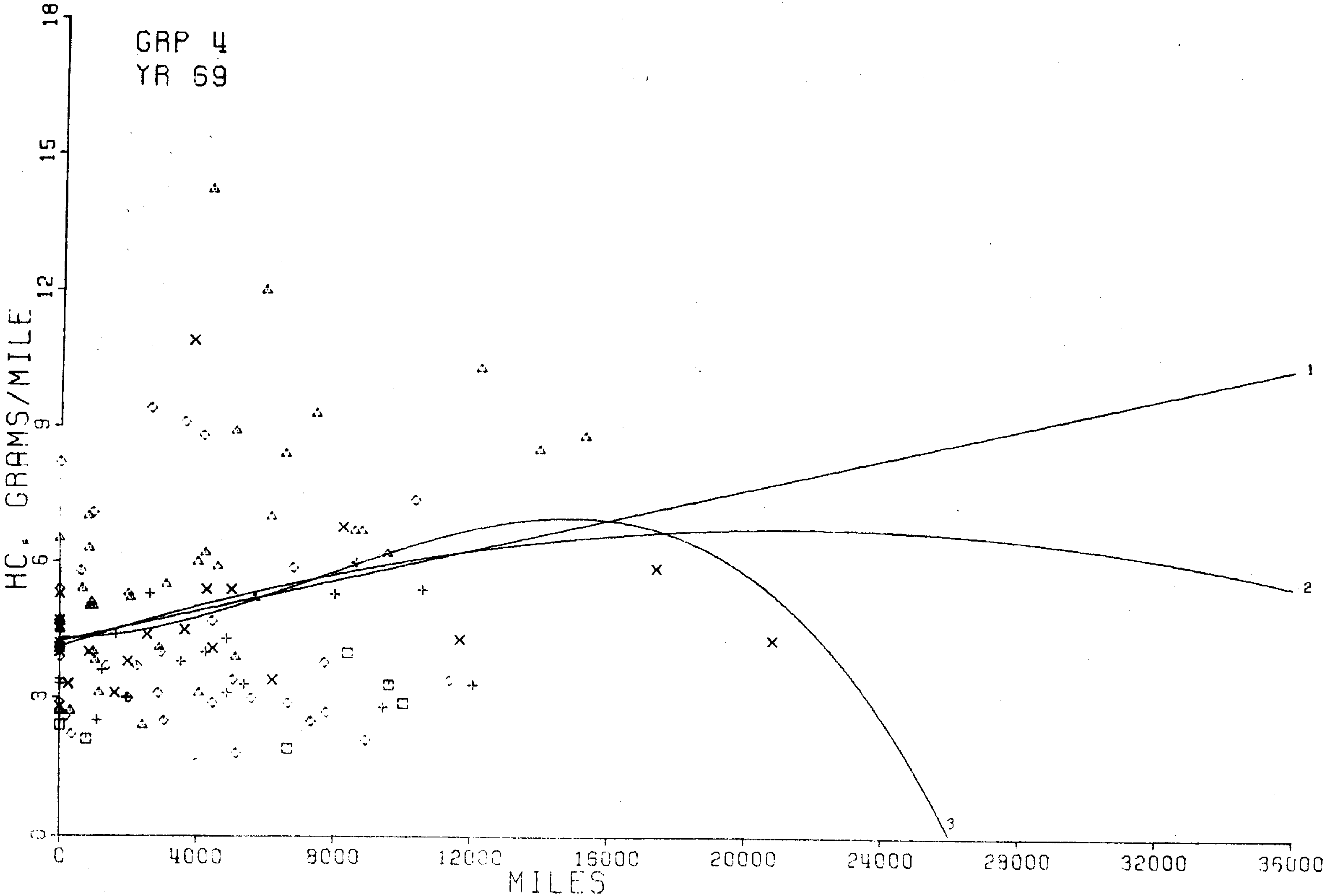


Figure A-88. DEGRADATION VS. MILES

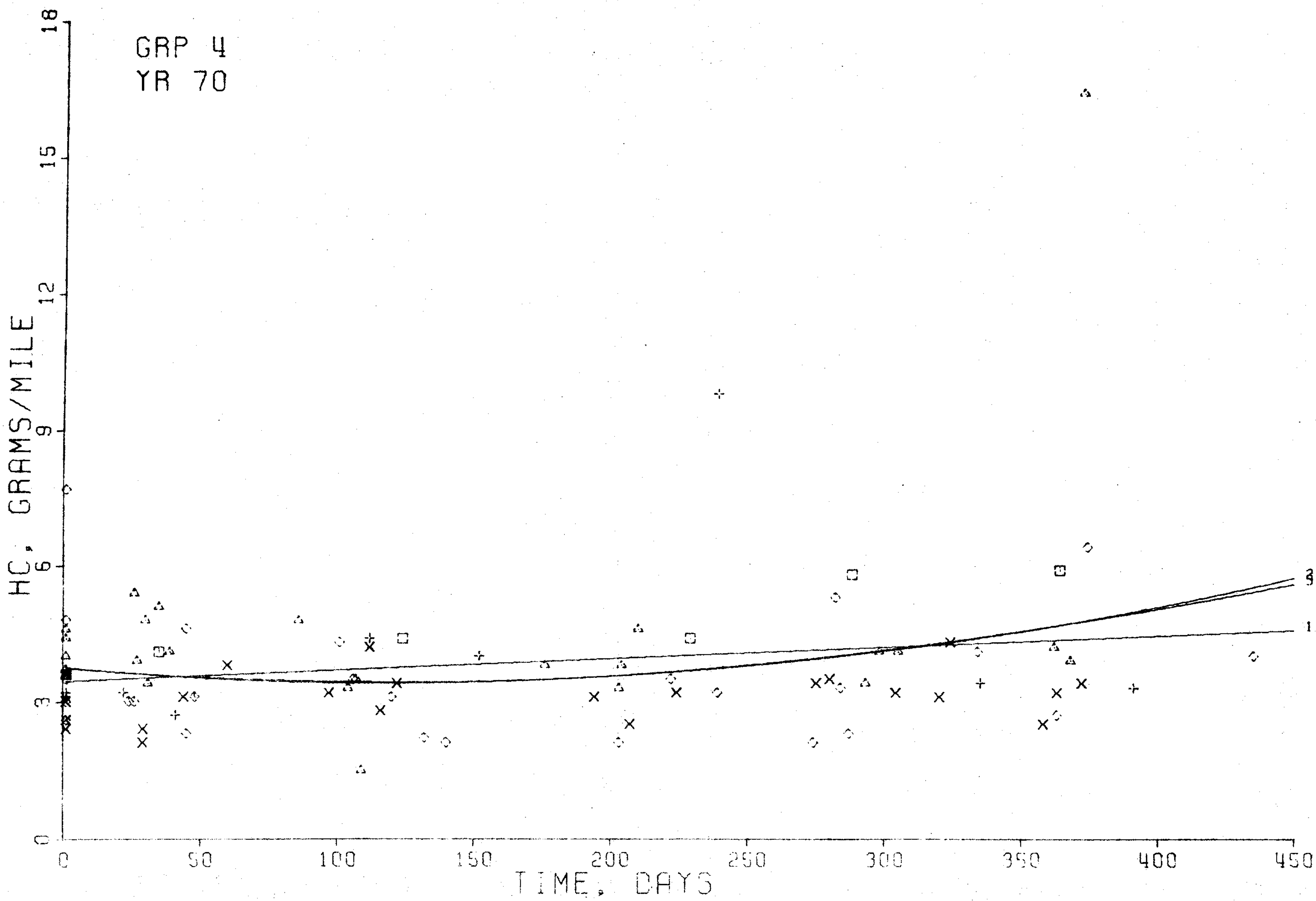


Figure A-89. DEGRADATION VS. TIME

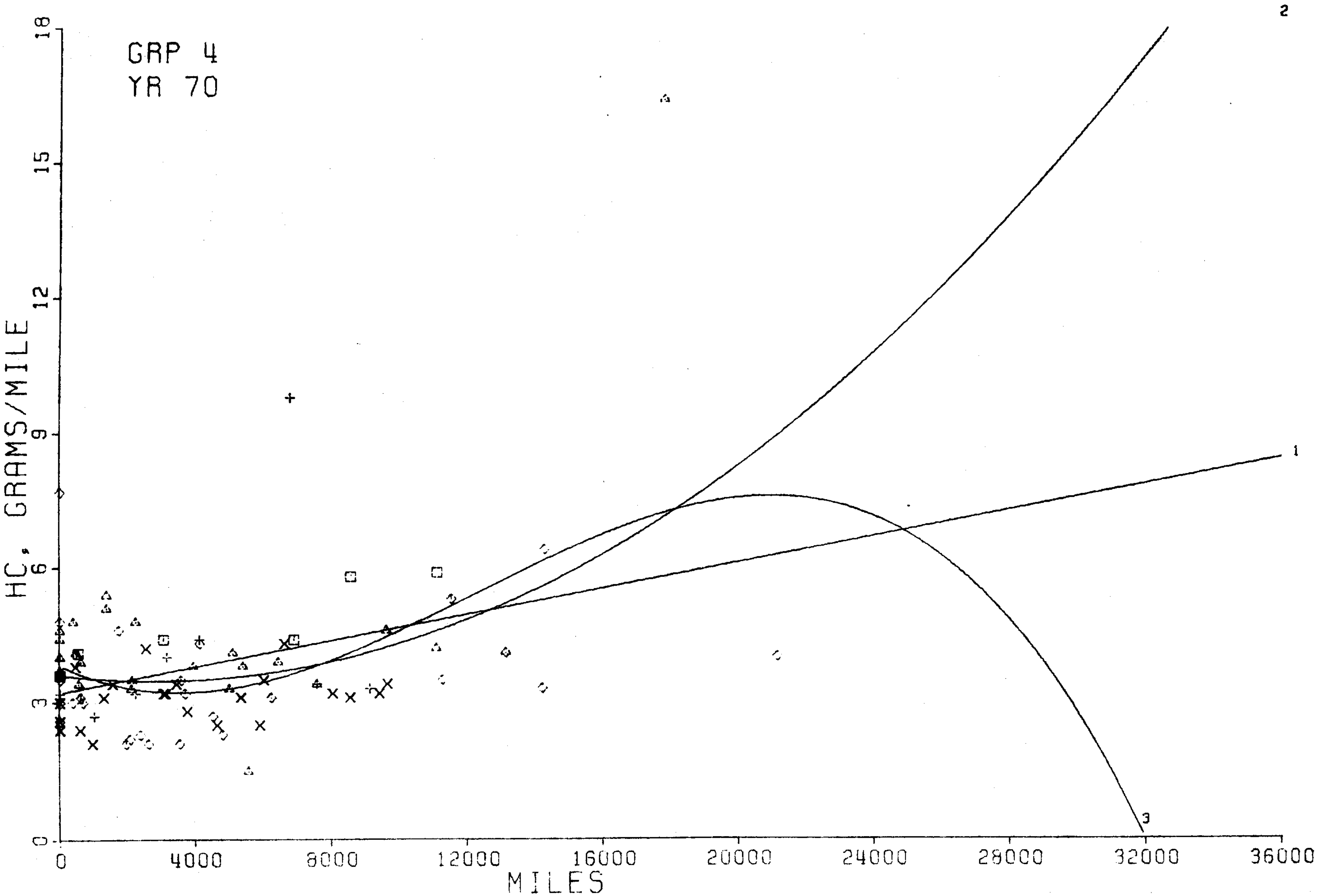


Figure A-90. DEGRADATION VS. MILES

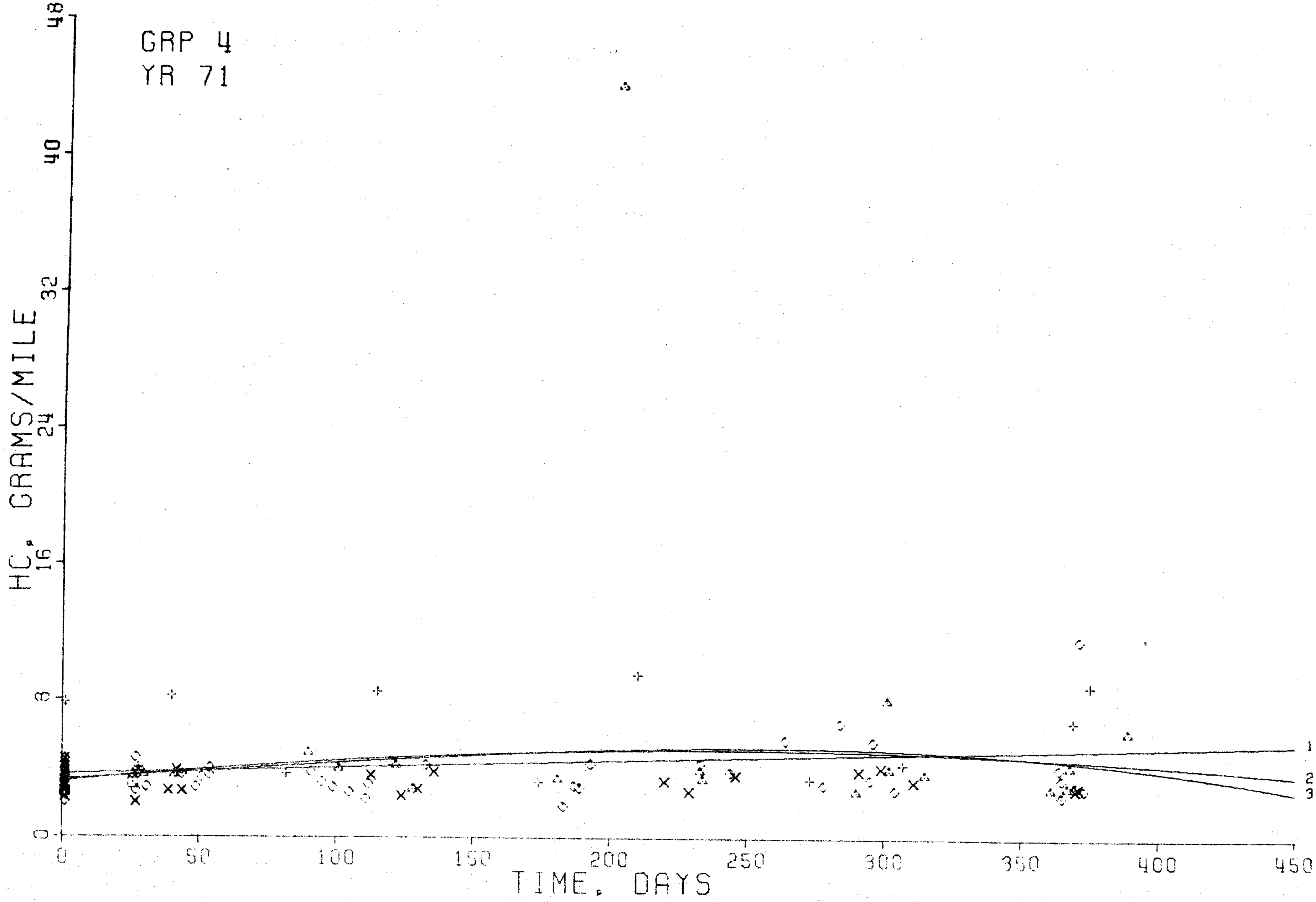
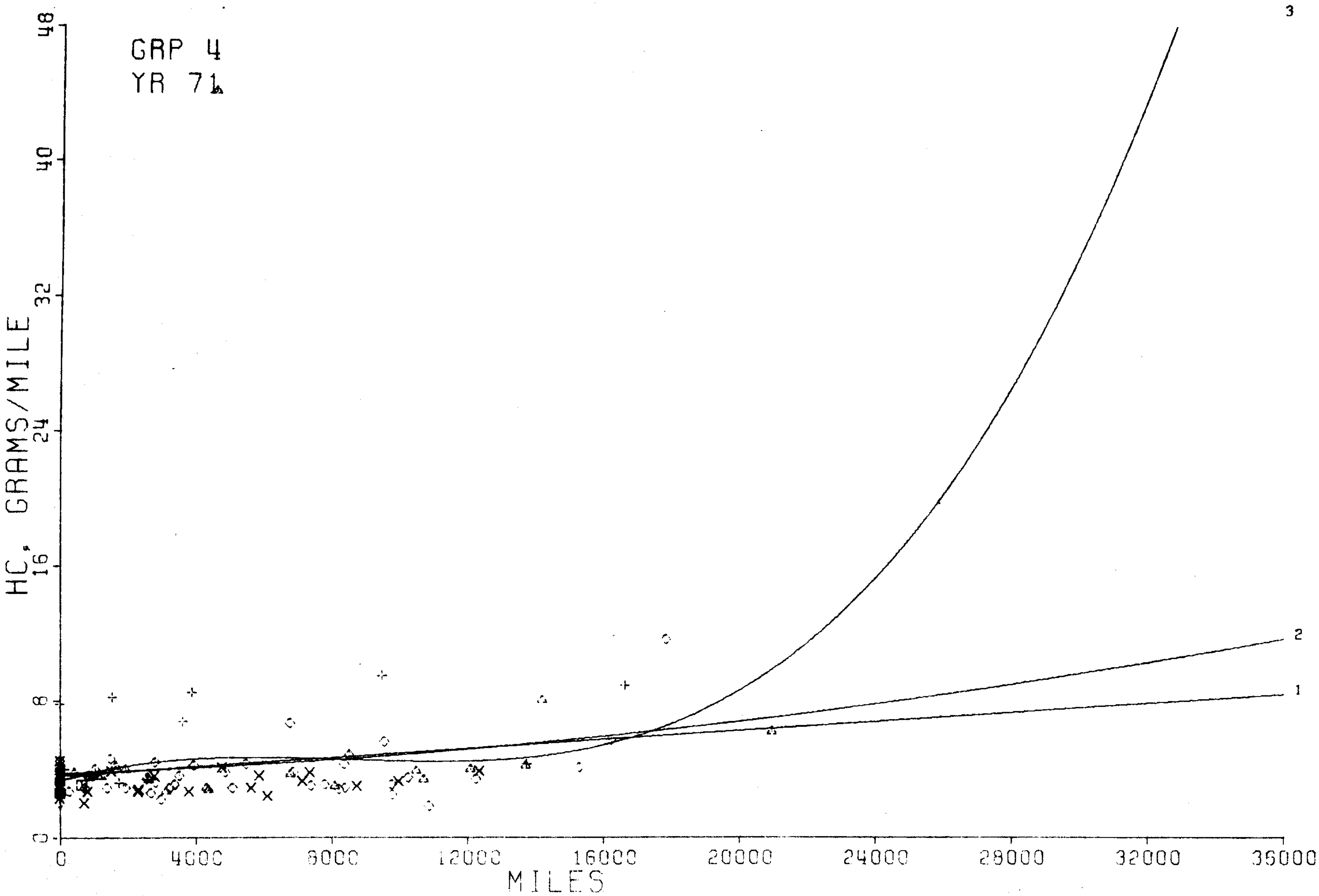


Figure A-91. DEGRADATION VS. TIME



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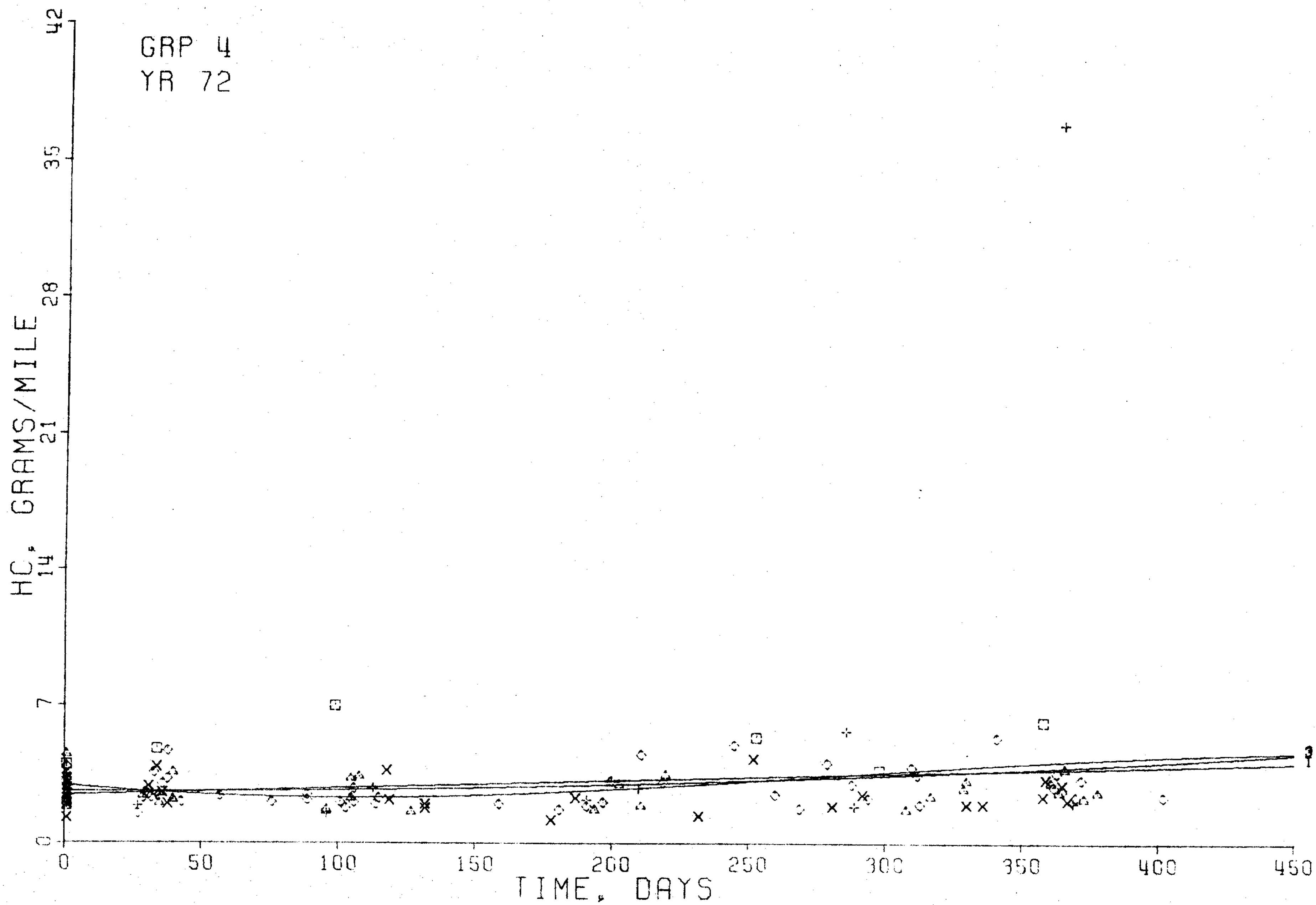

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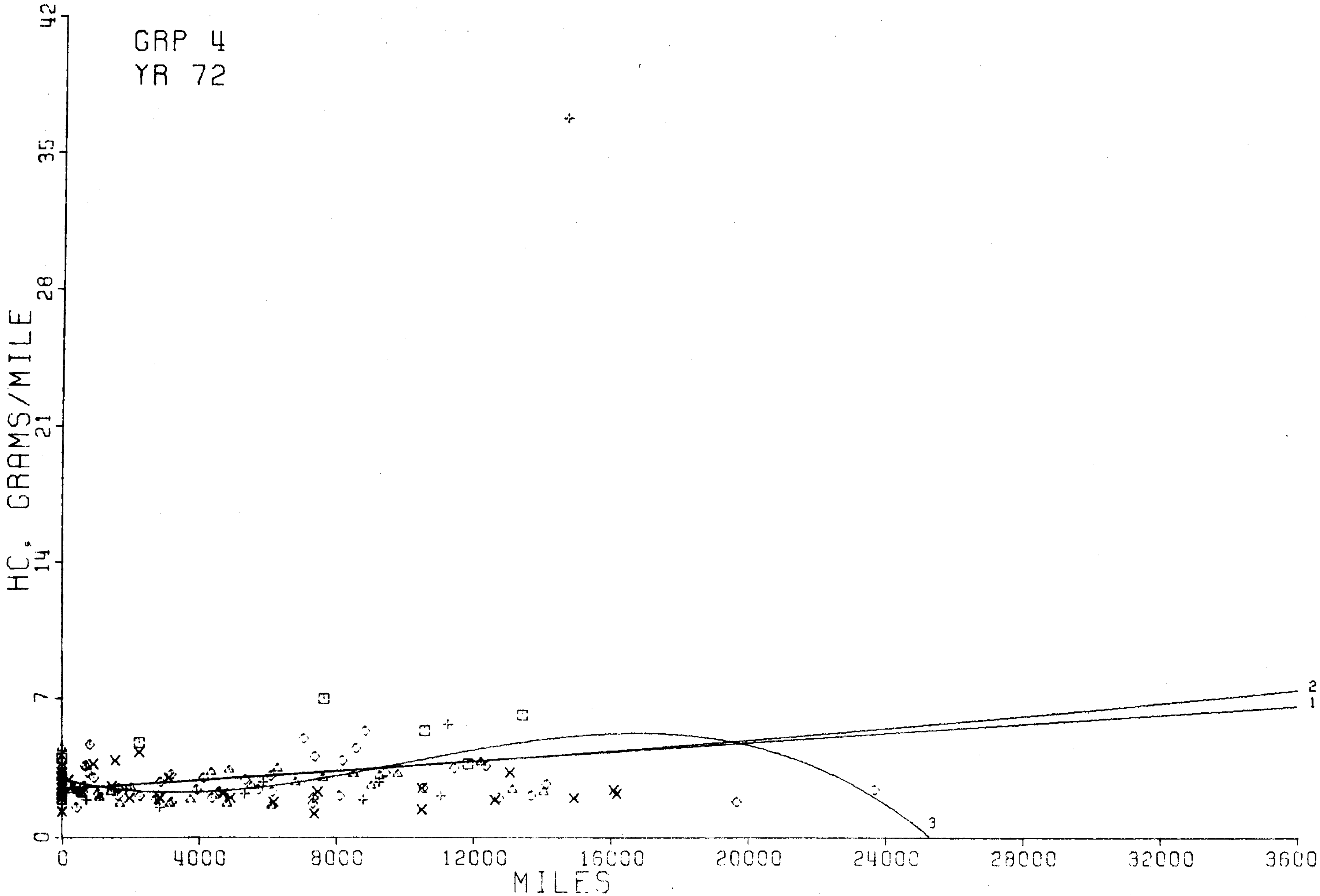
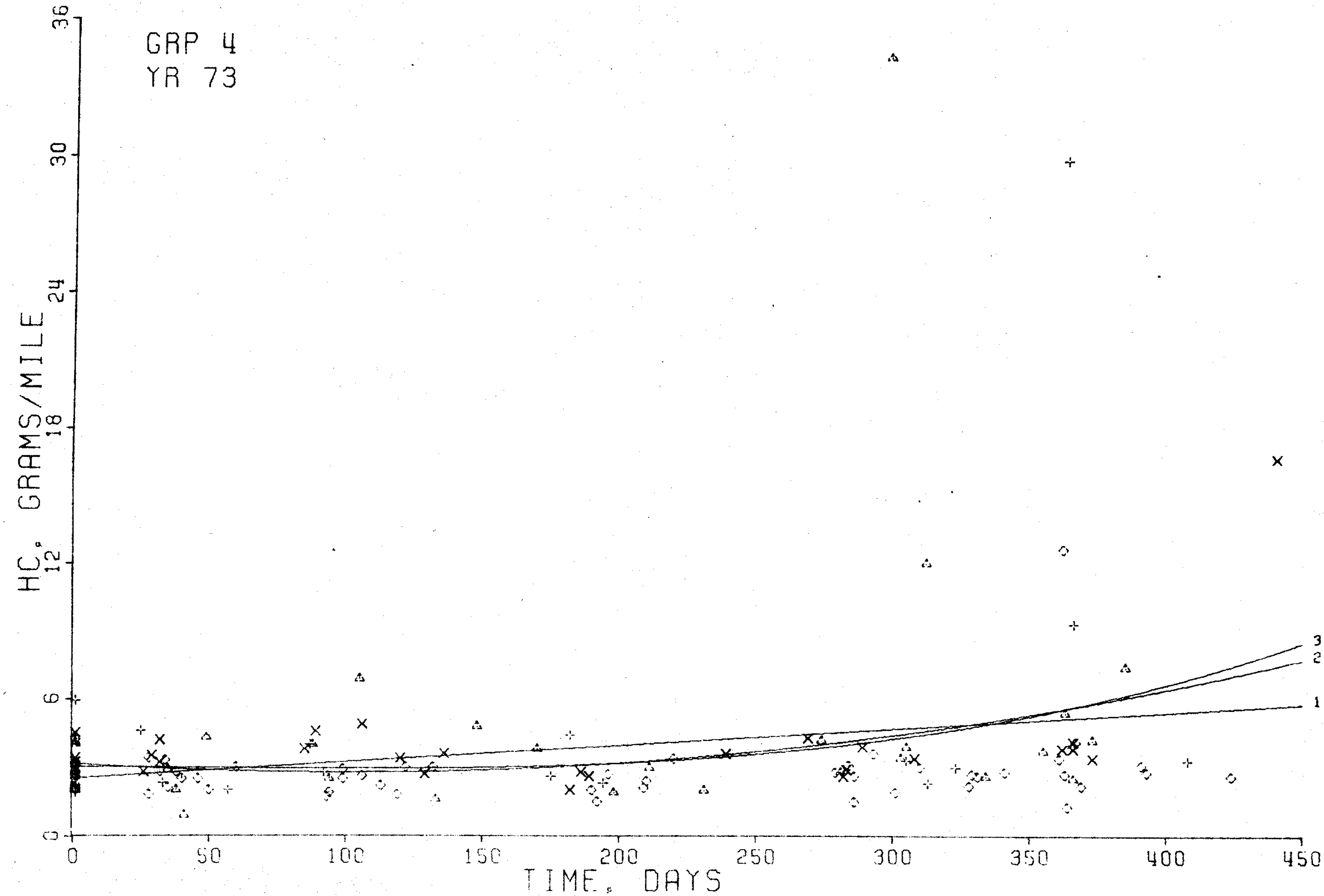


Figure A-94. DEGRADATION VS. MILES



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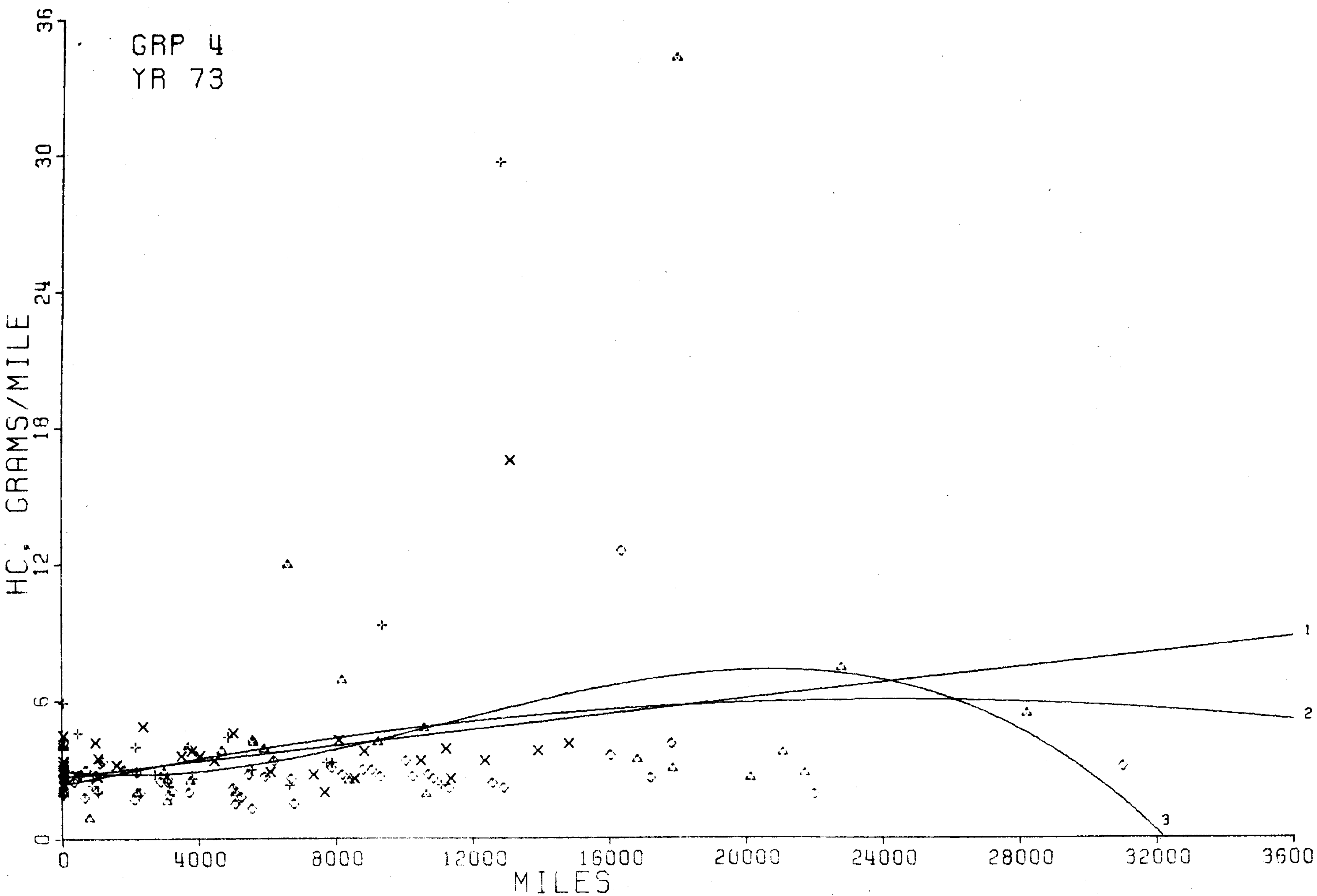


Figure A-96. DEGRADATION VS. MILES

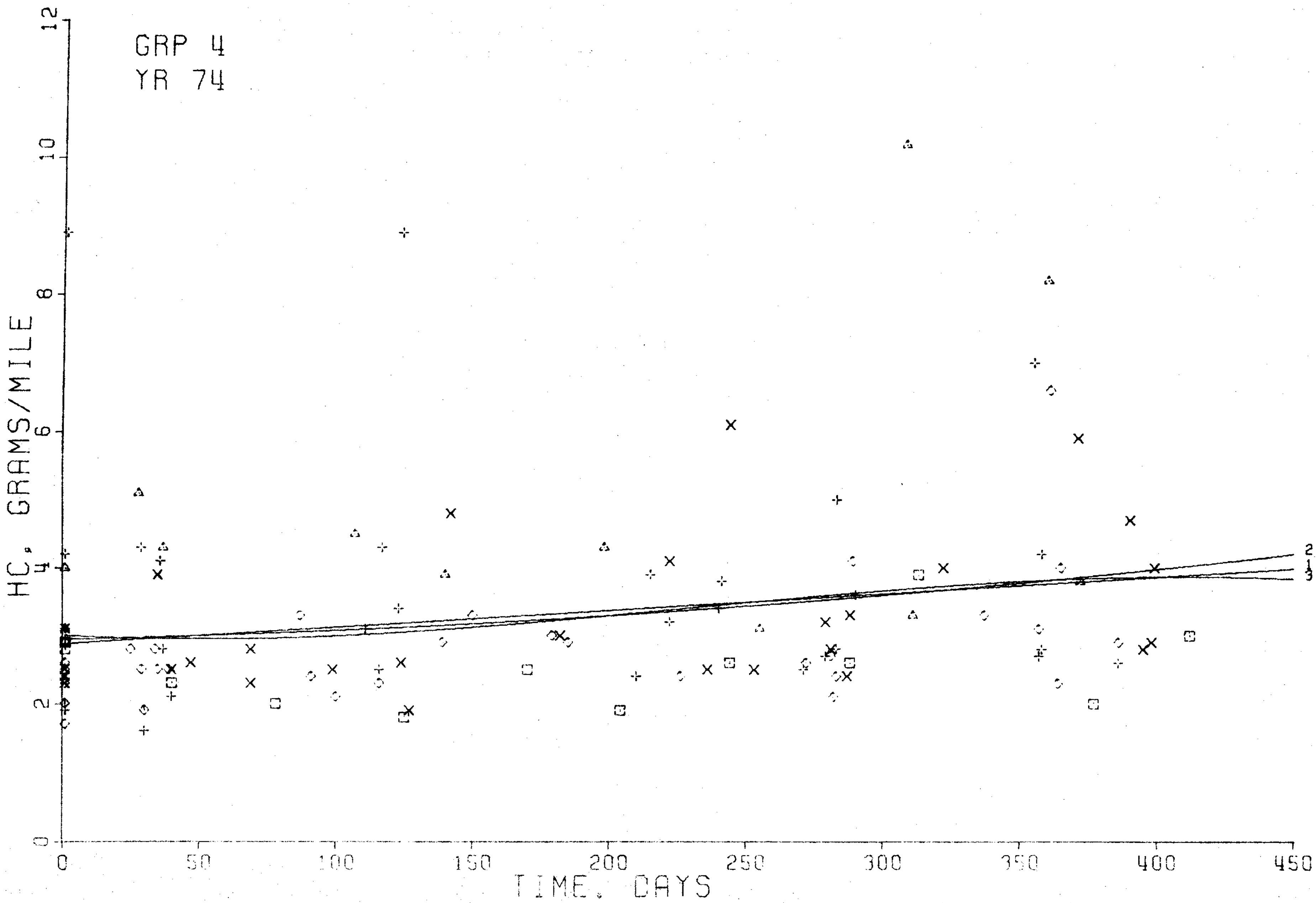


Figure A-97. DEGRADATION VS. TIME

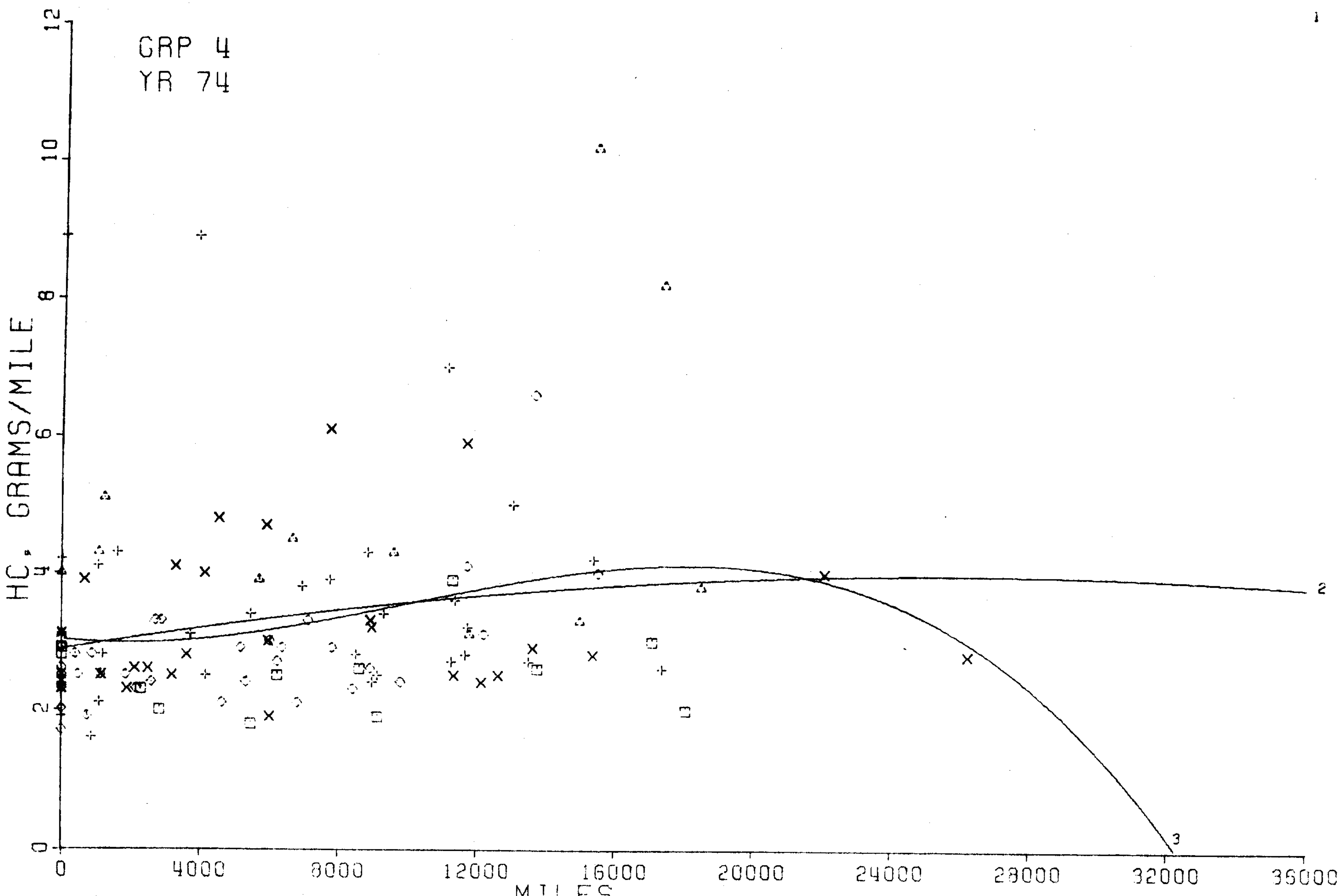


Figure A-98. DEGRADATION VS. MILES

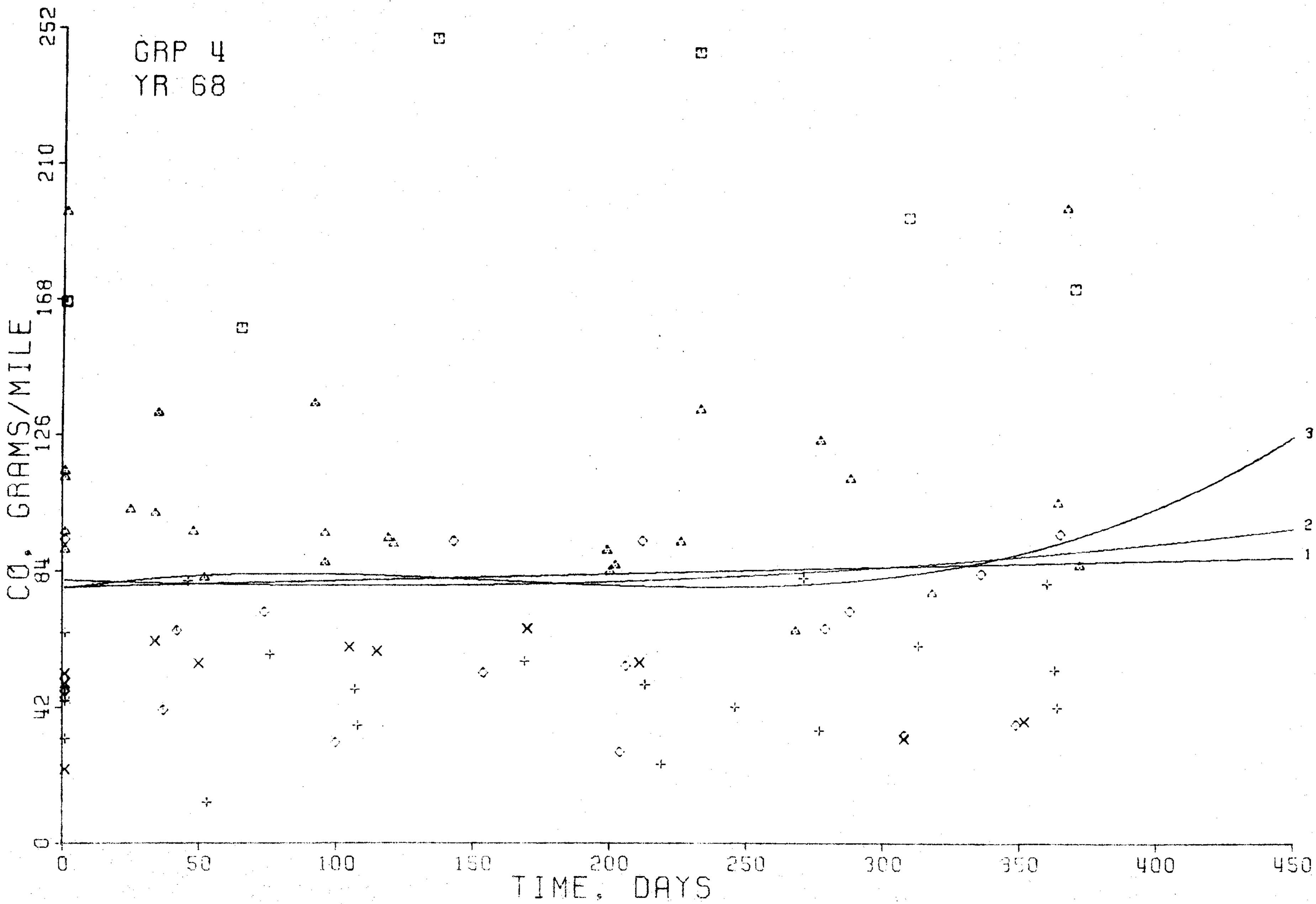


Figure A-99. DEGRADATION VS. TIME

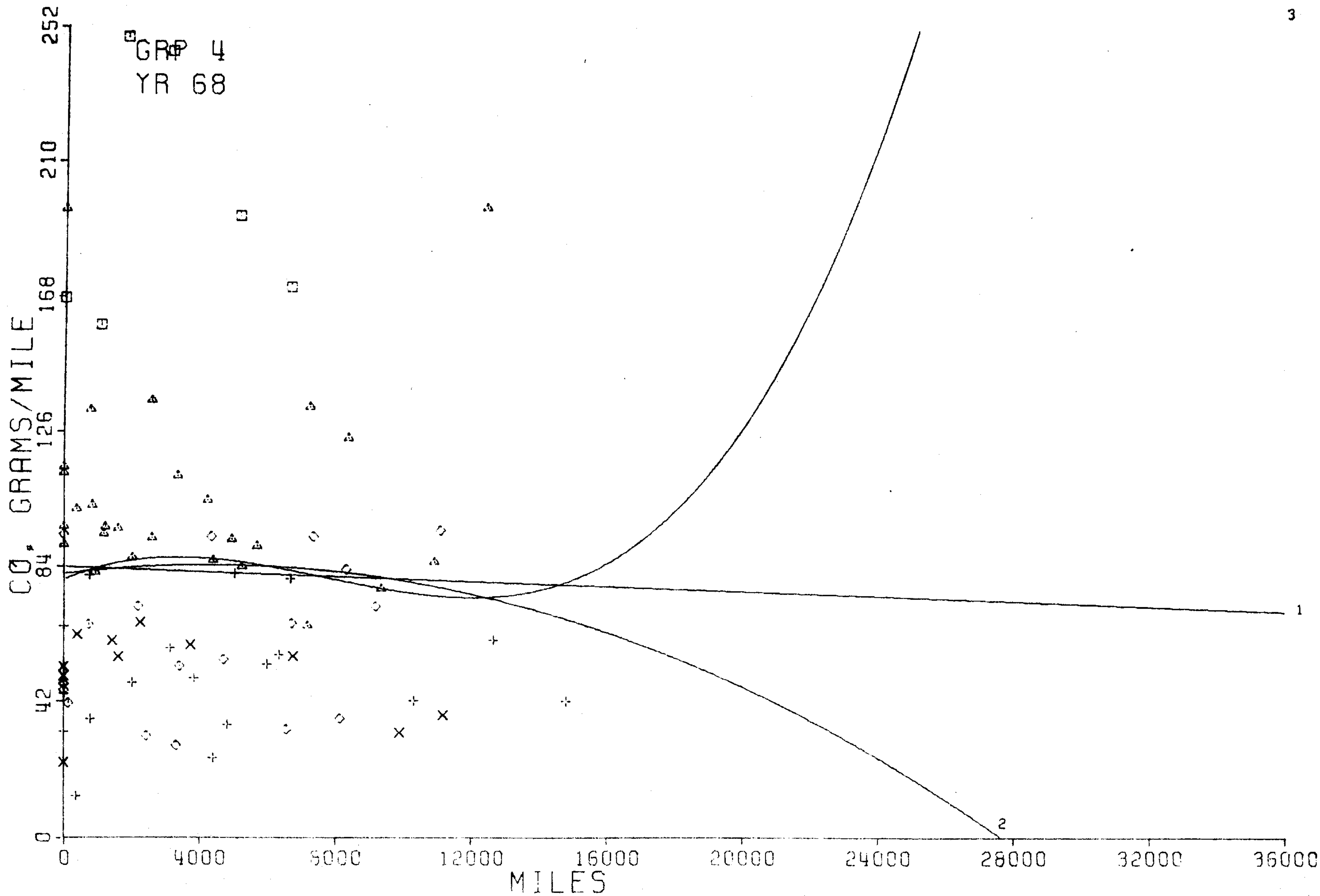


Figure A-100. DEGRADATION VS. MILES

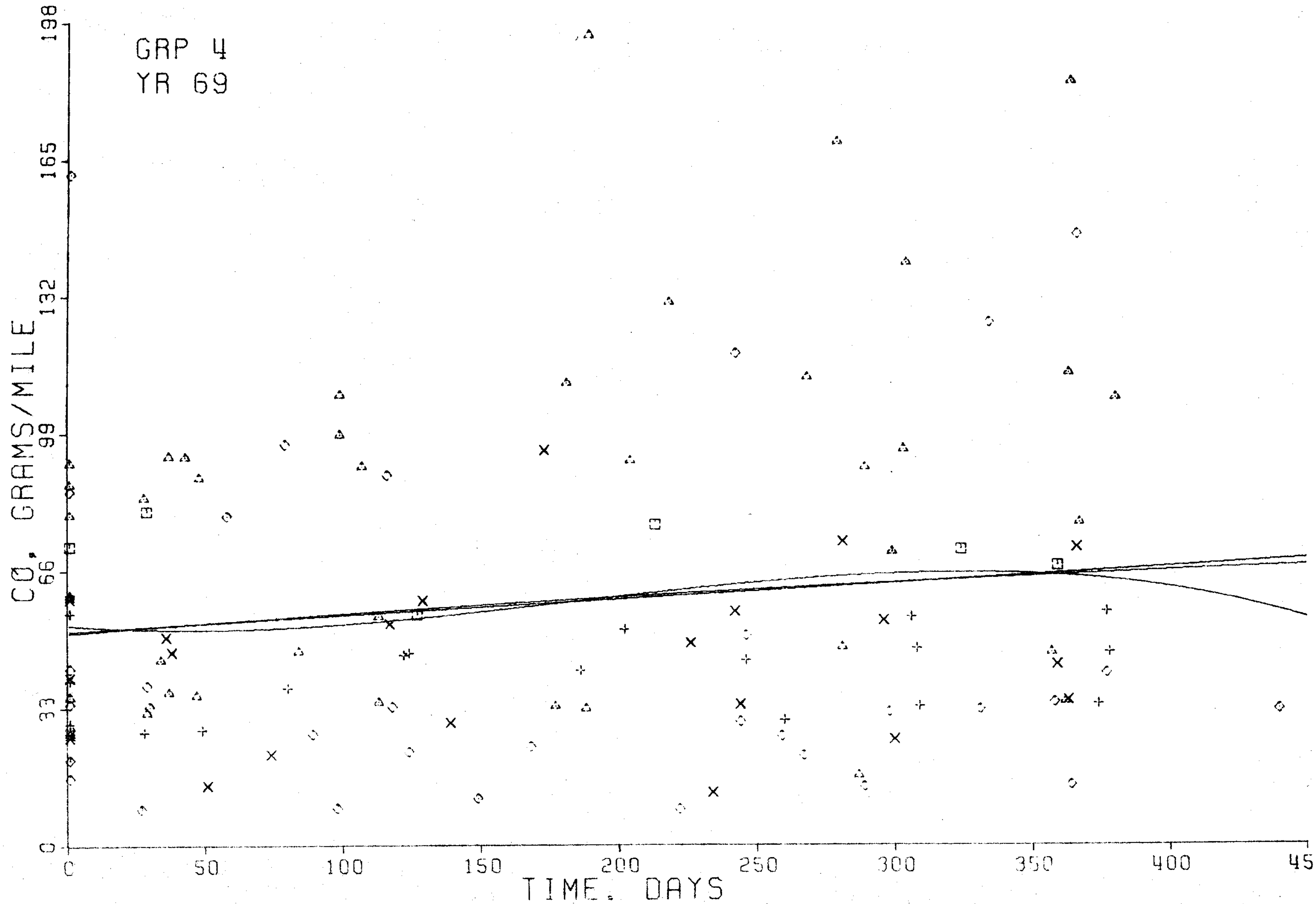


Figure A-101. DEGRADATION VS. TIME

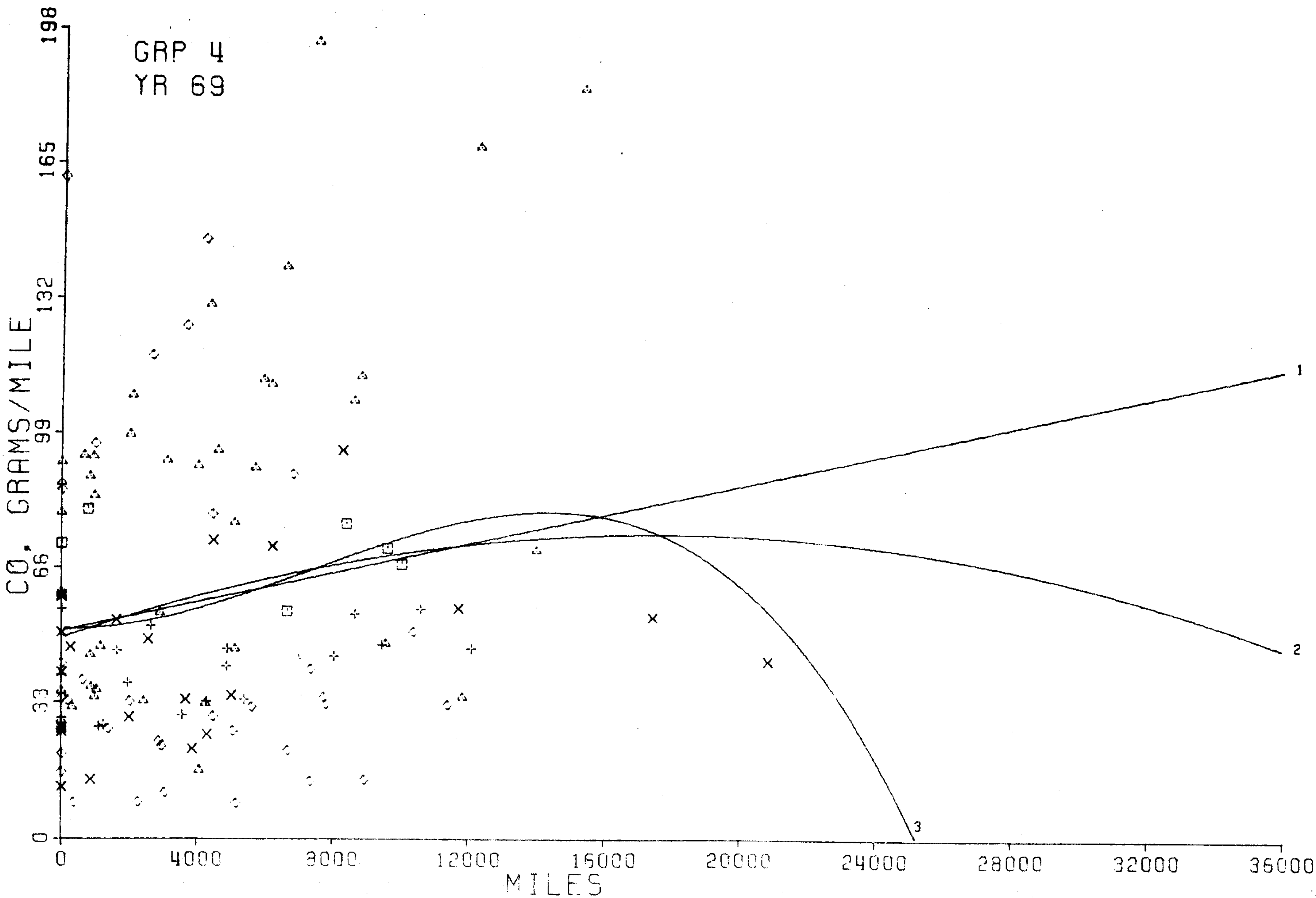


Figure A-102. DEGRADATION VS. MILES

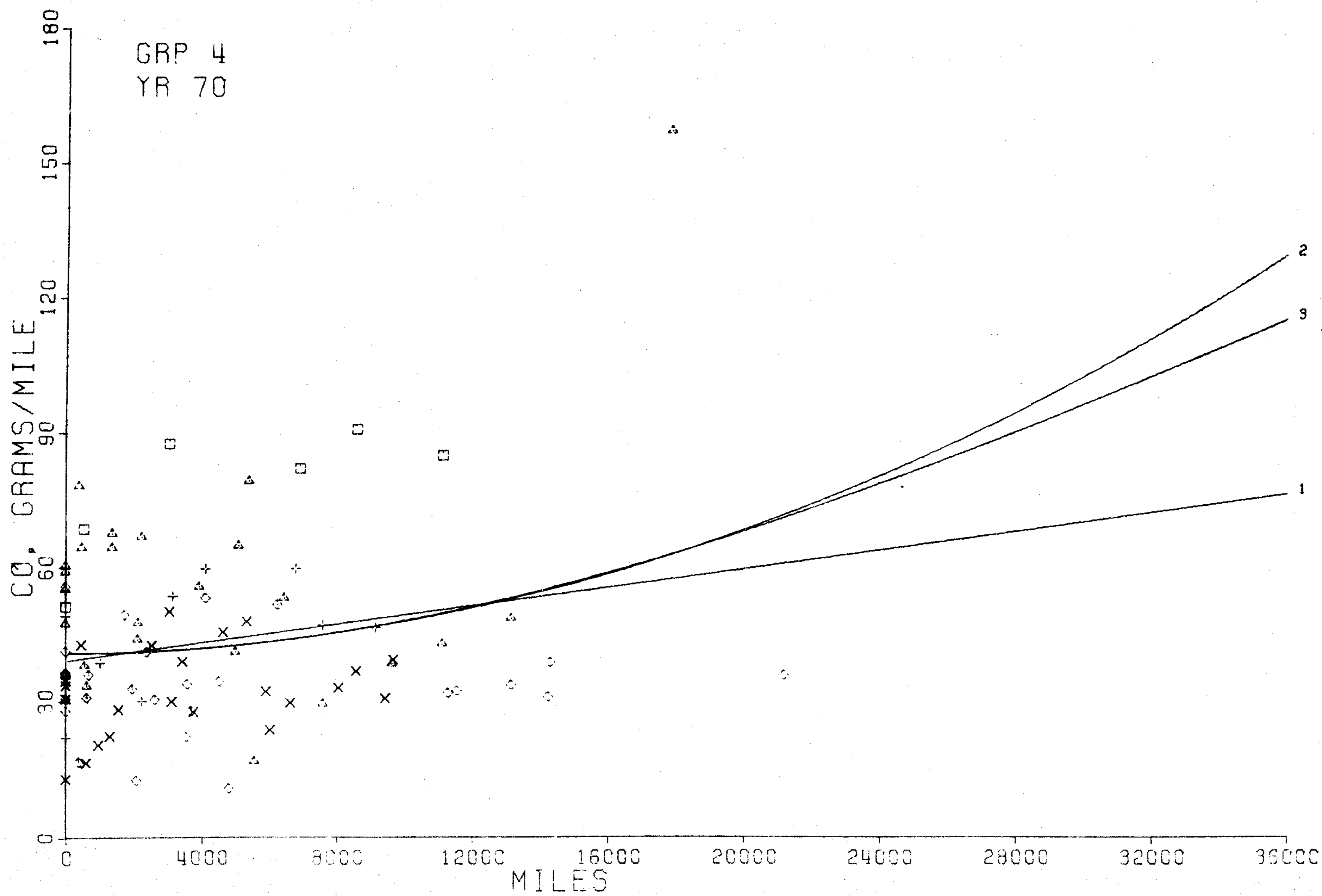
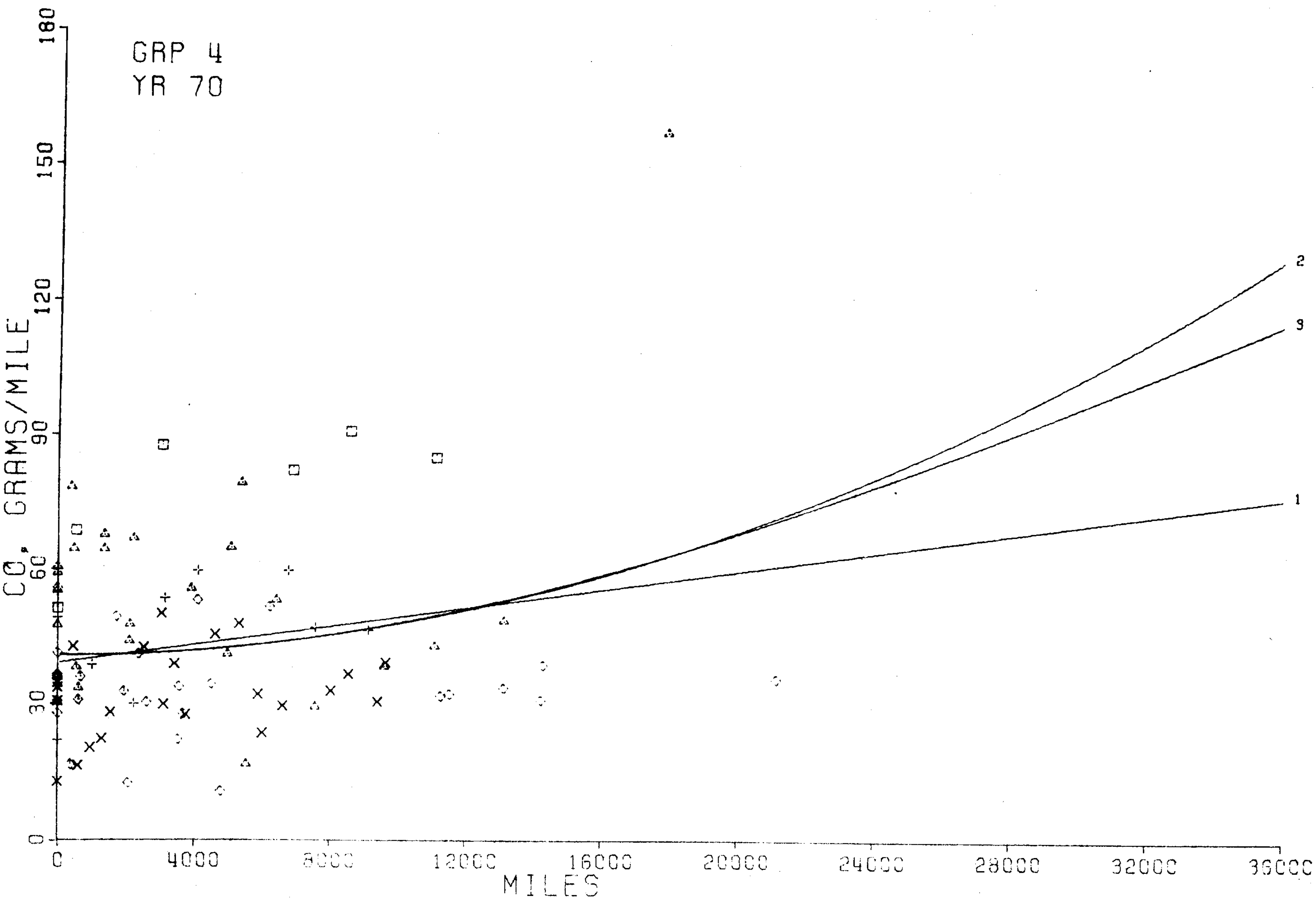


Figure A-104. DEGRADATION VS. MILES



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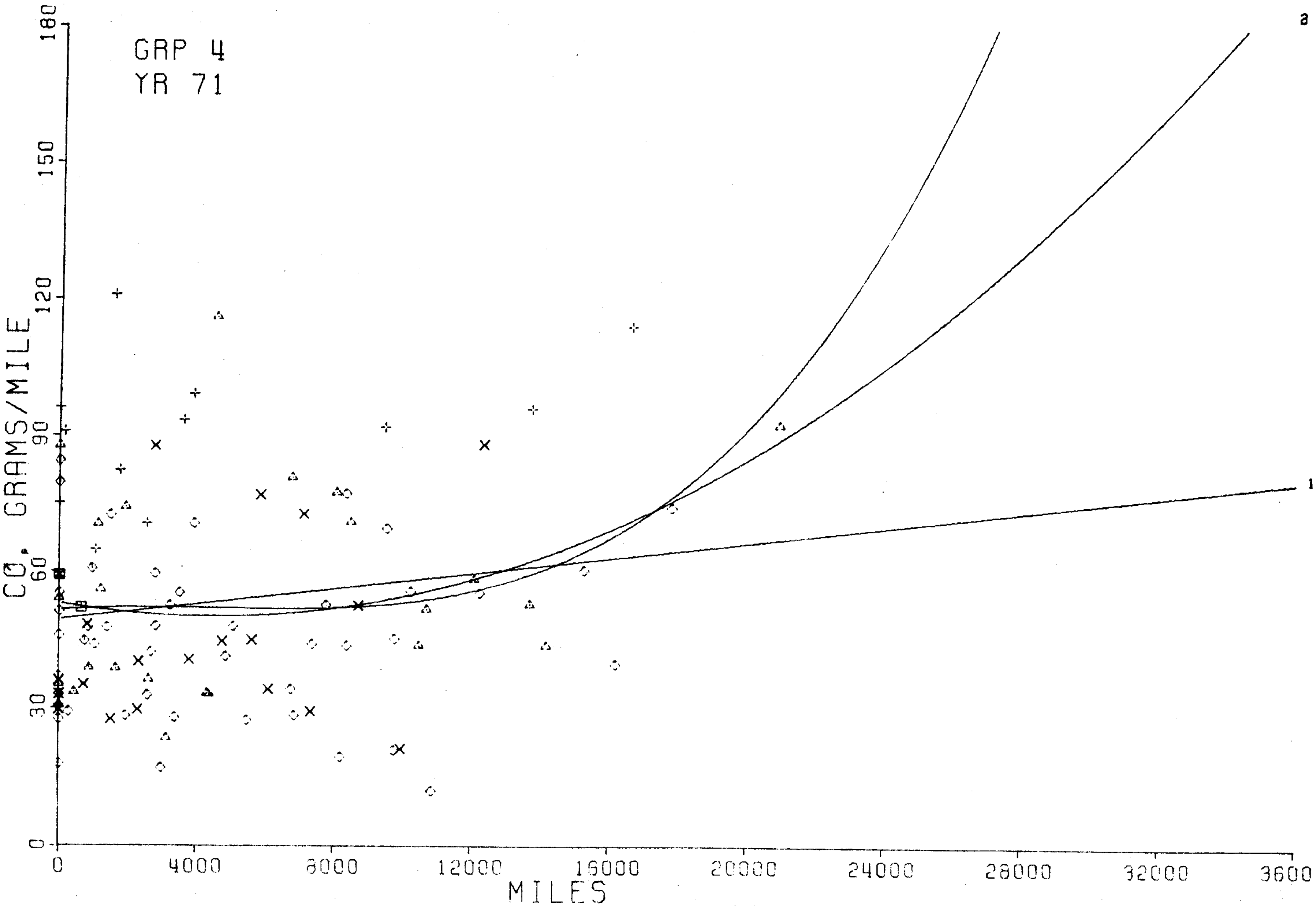


Figure A-106. DEGRADATION VS. MILES

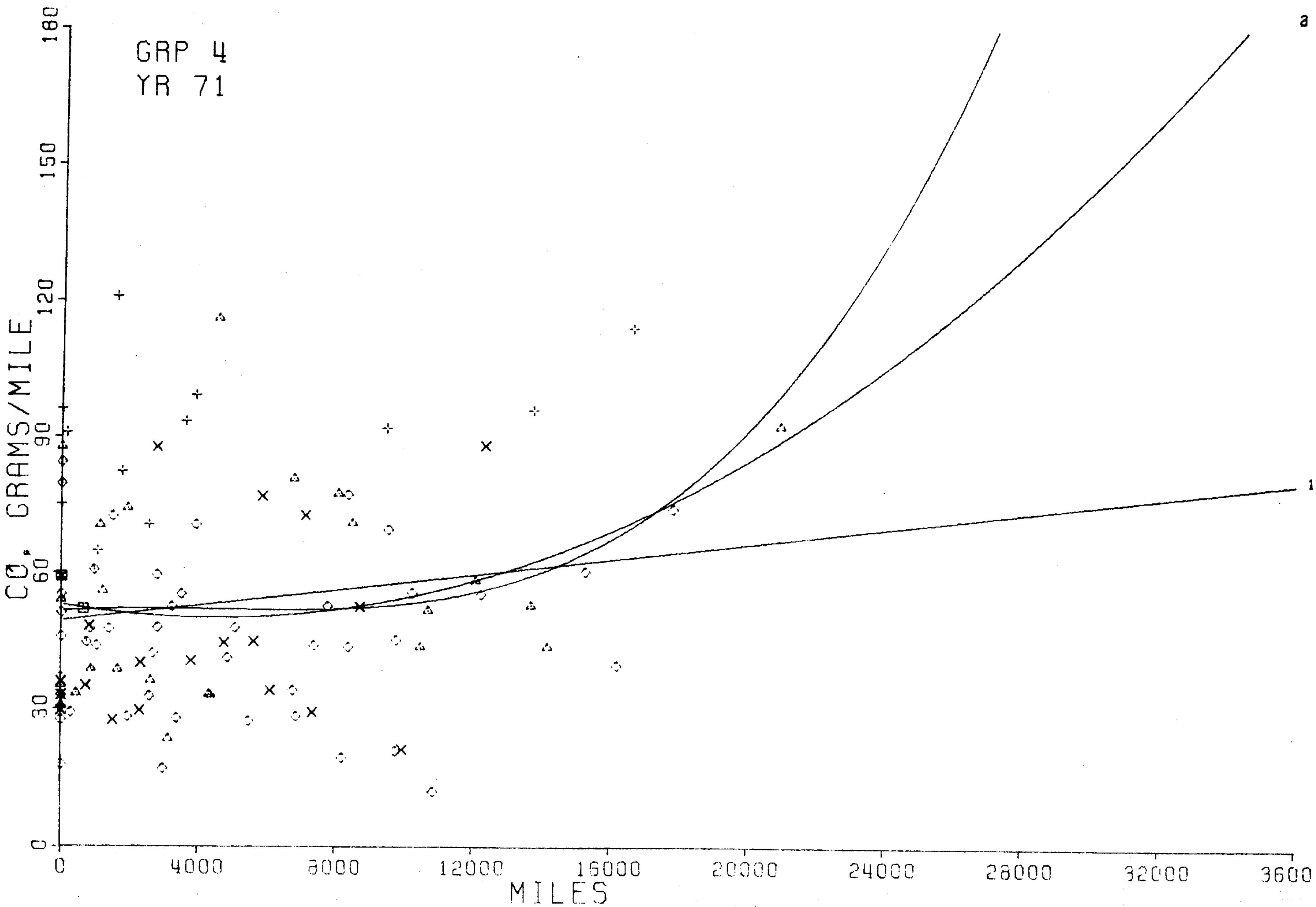
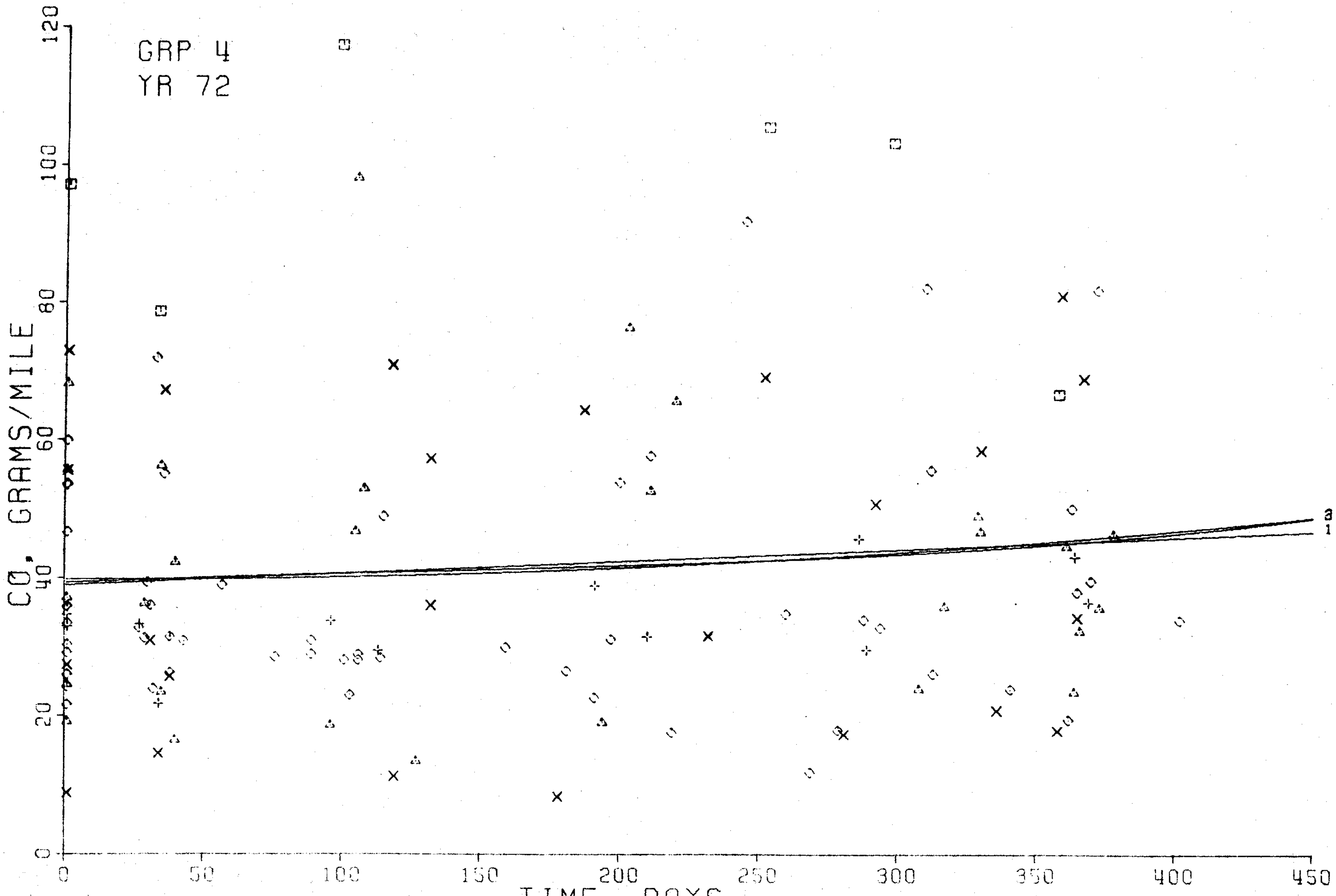


Figure A-106. DEGRADATION VS. MILES



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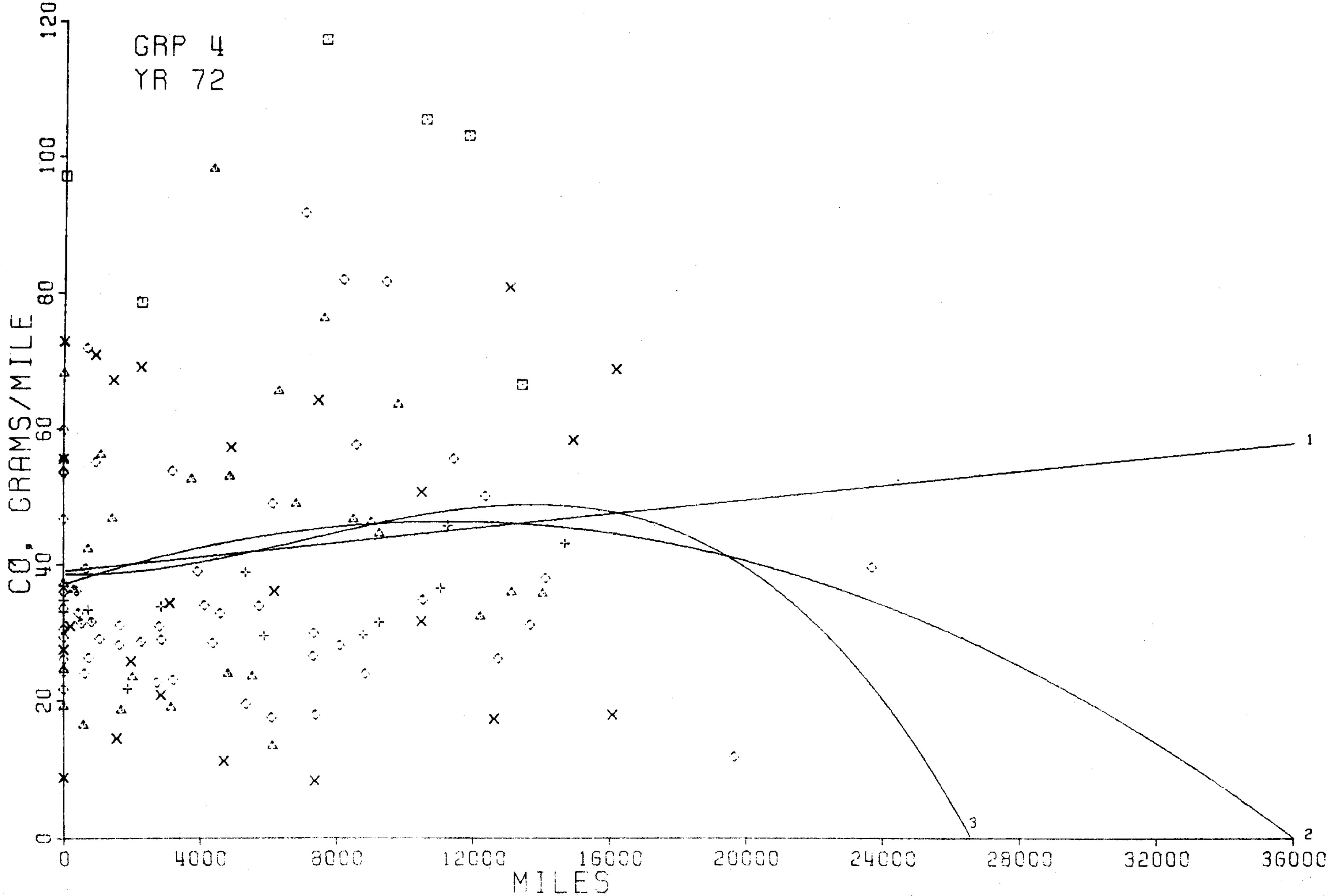


Figure A-108. DEGRADATION VS. MILES

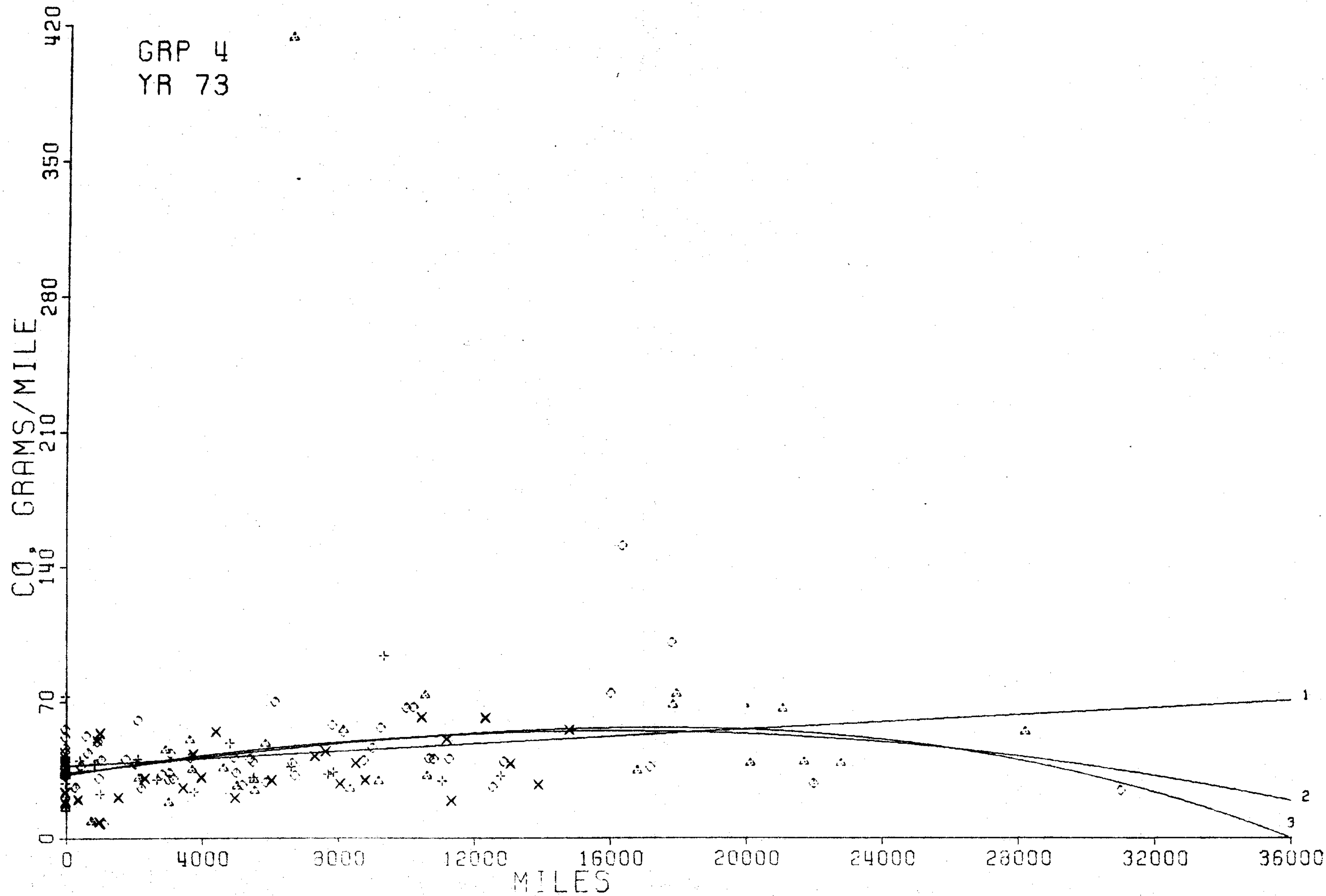
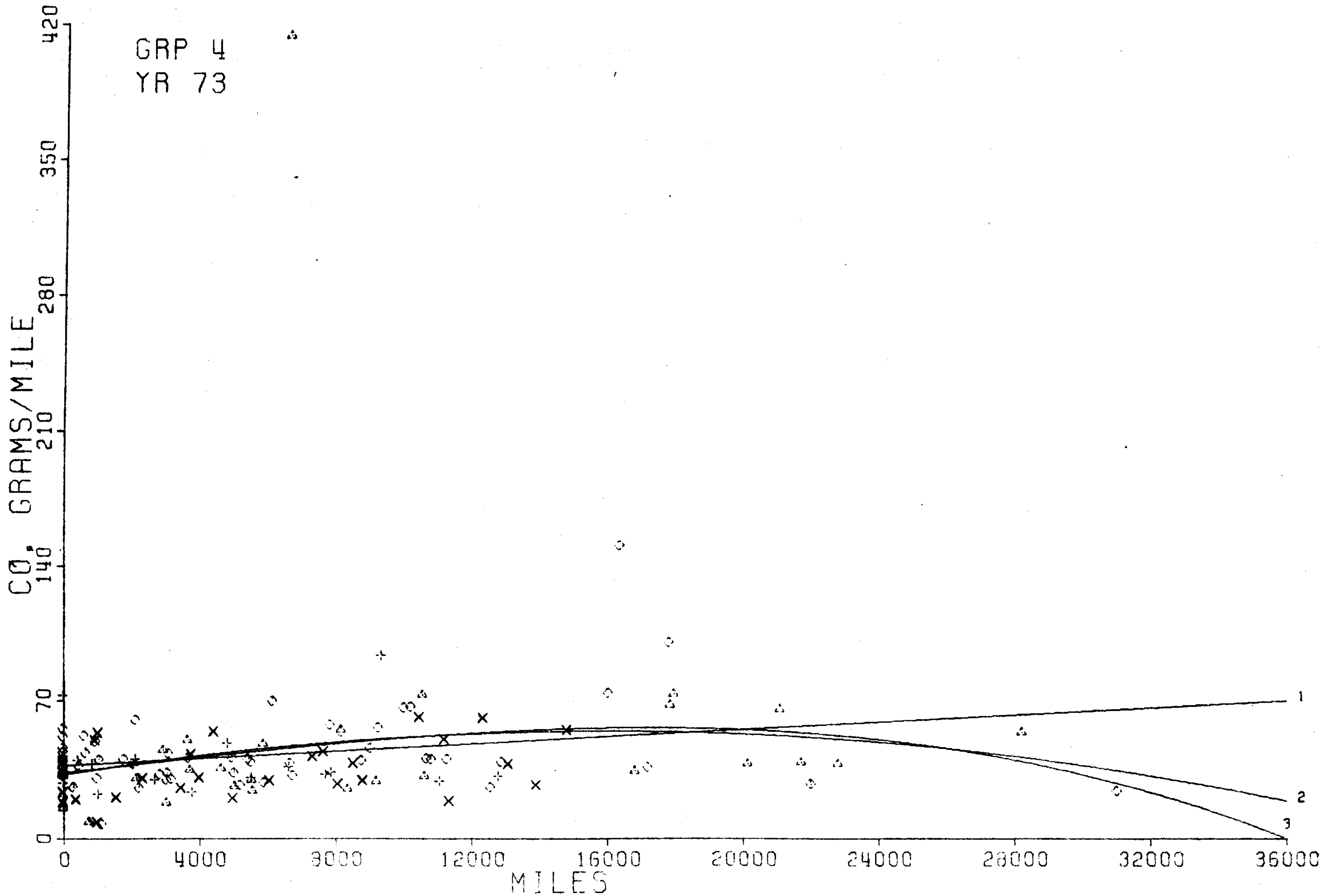


Figure A-110. DEGRADATION VS. MILES



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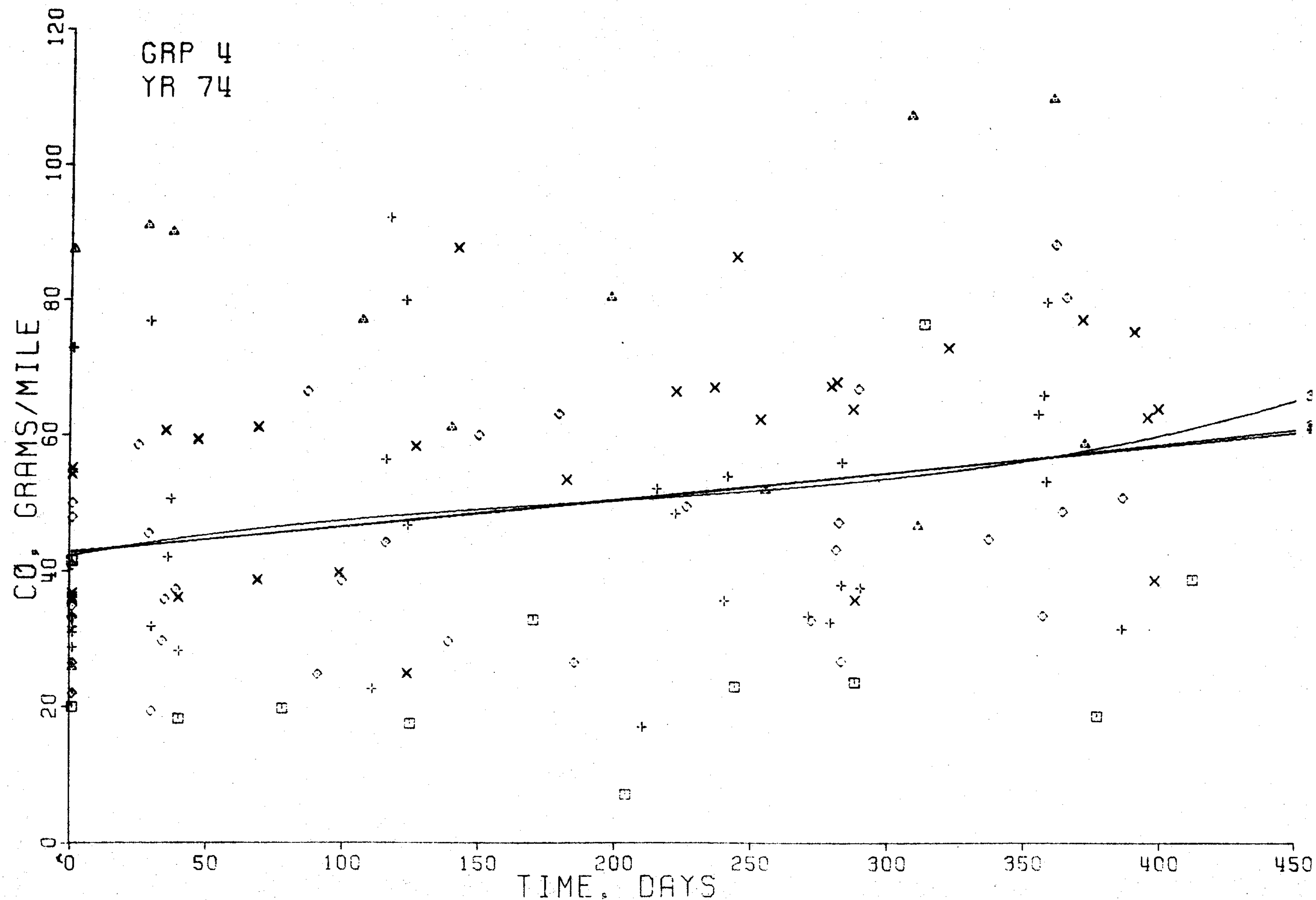


Figure A-111. DEGRADATION VS. TIME

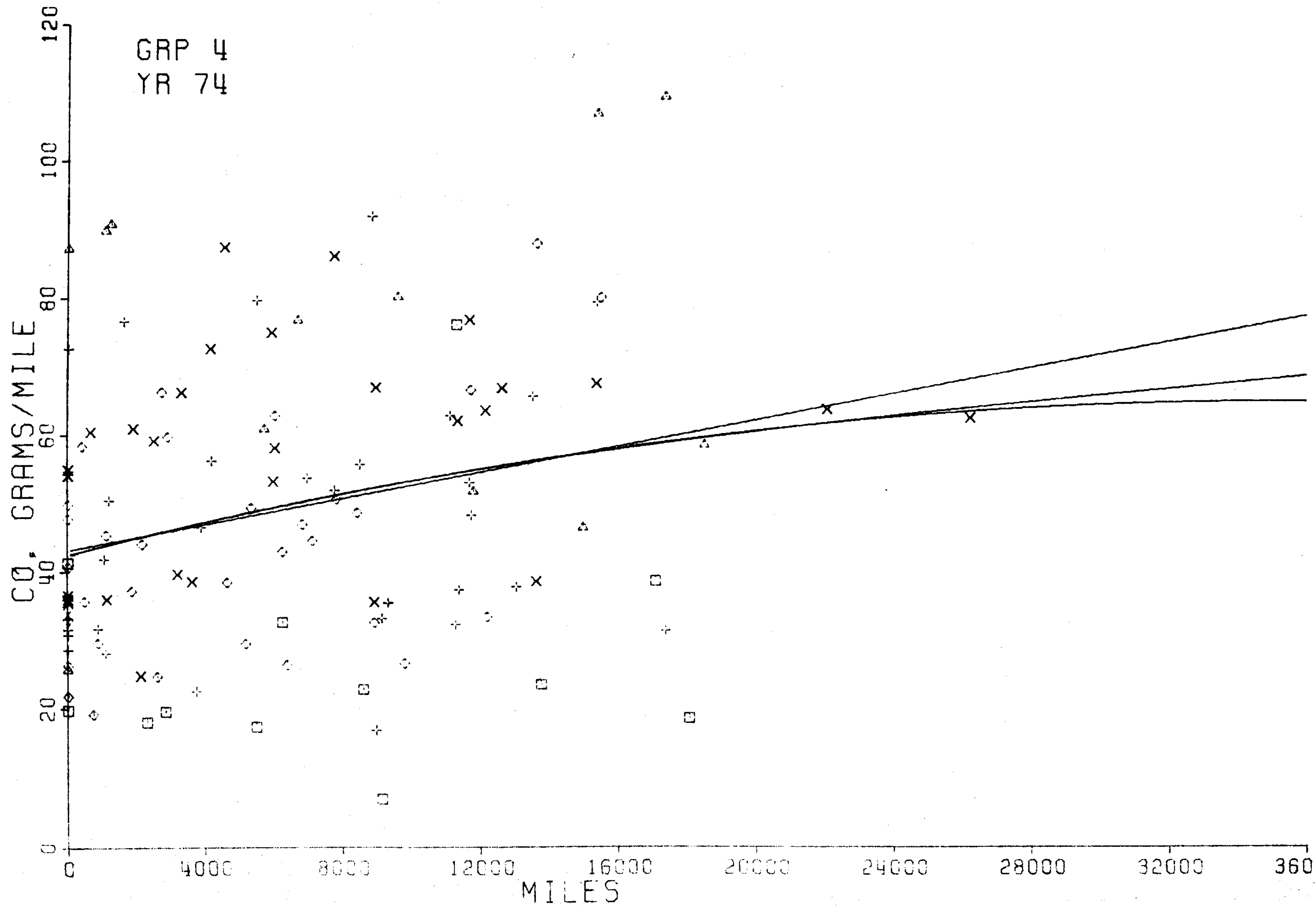


Figure A-112. DEGRADATION VS. MILES

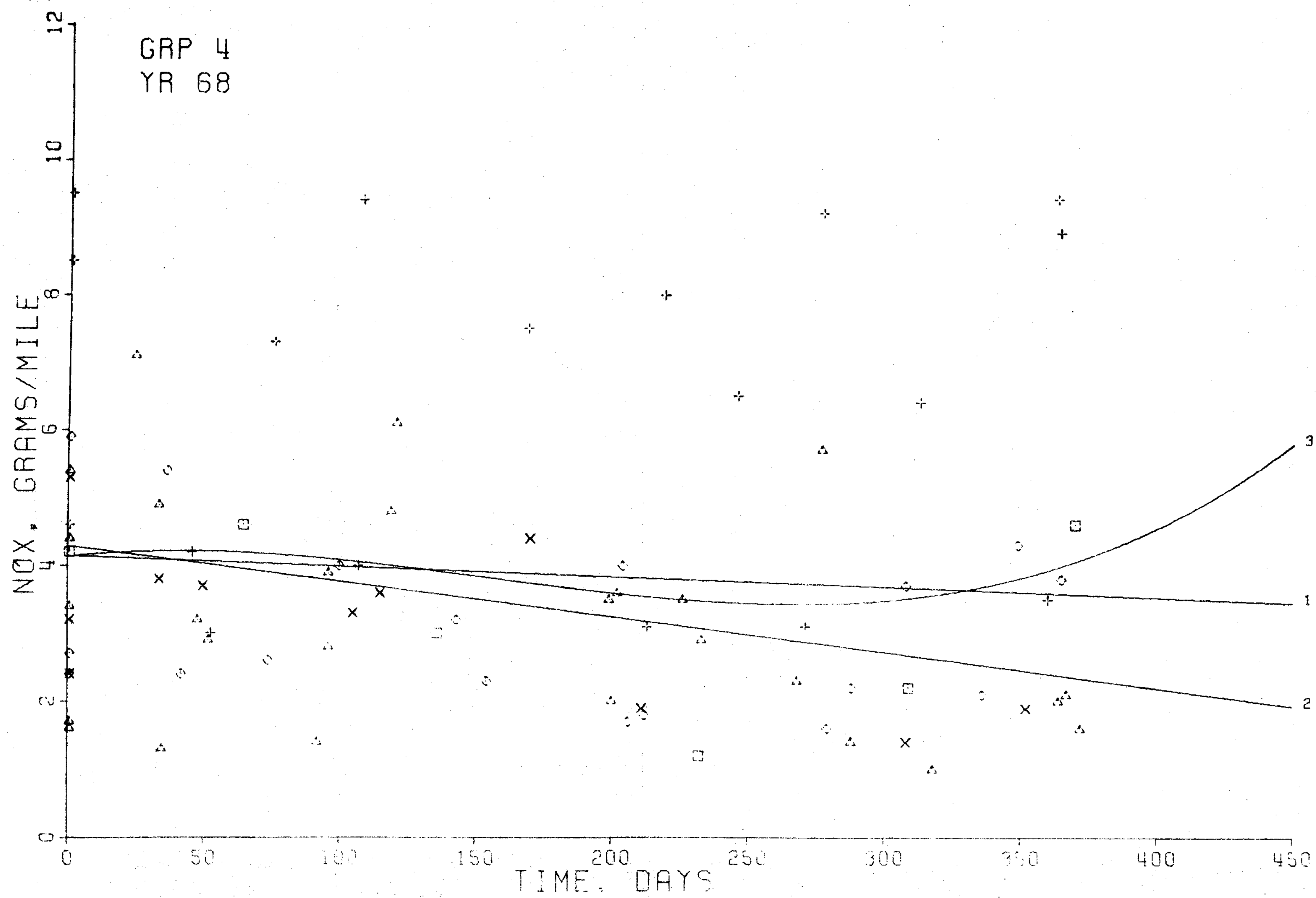


Figure A-113. DEGRADATION VS. TIME

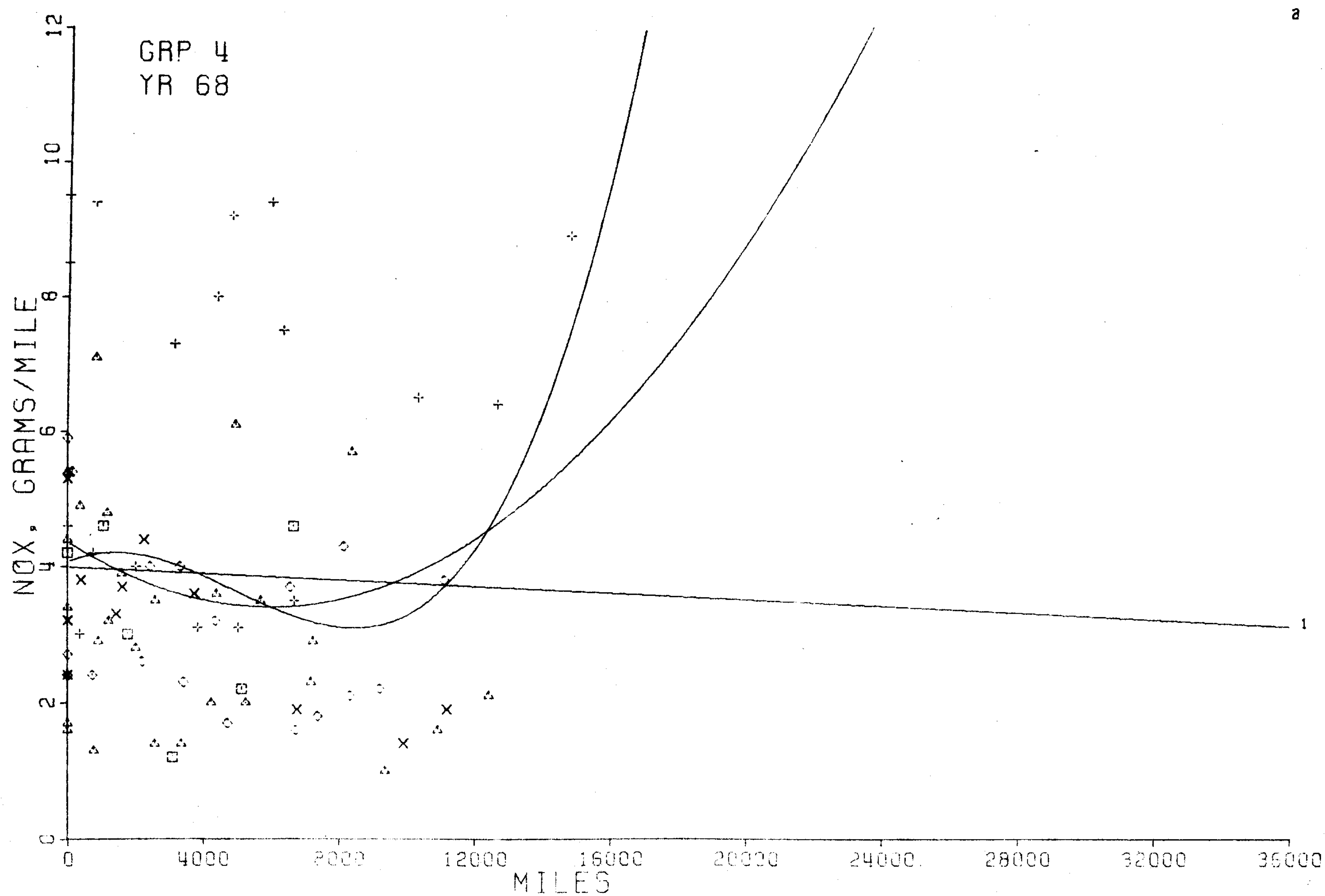


Figure A-114. DEGRADATION VS. MILES

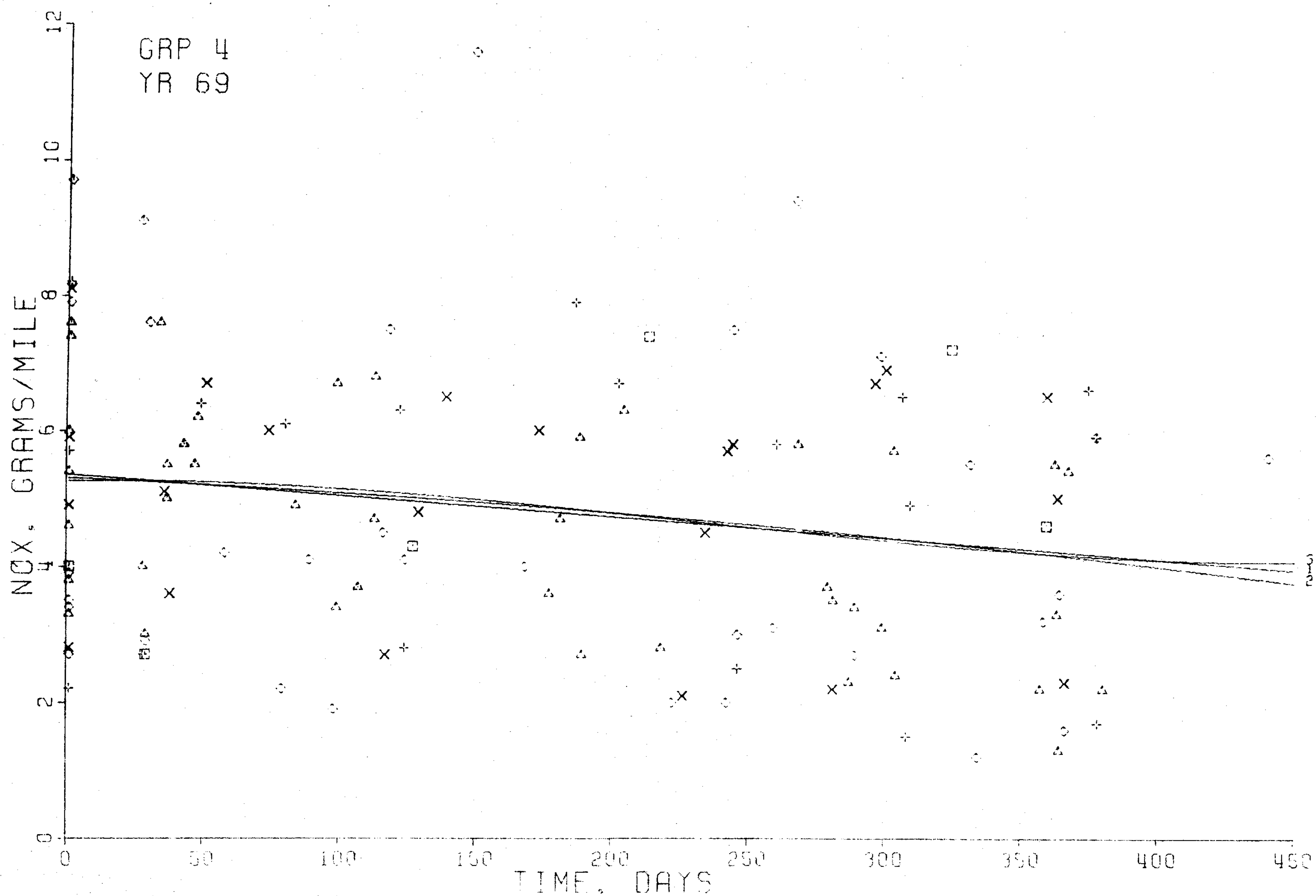


Figure A-115. DEGRADATION VS. TIME

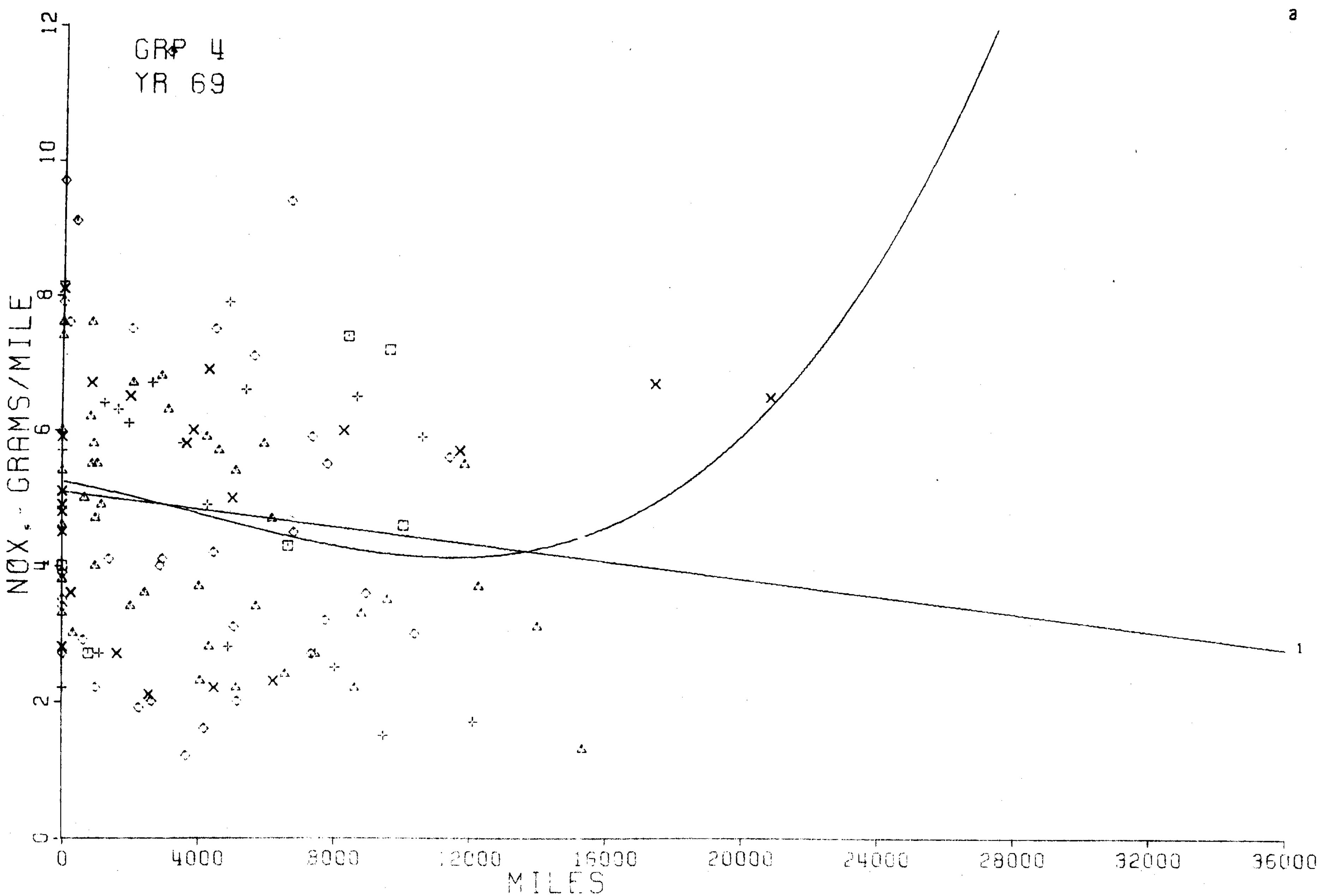
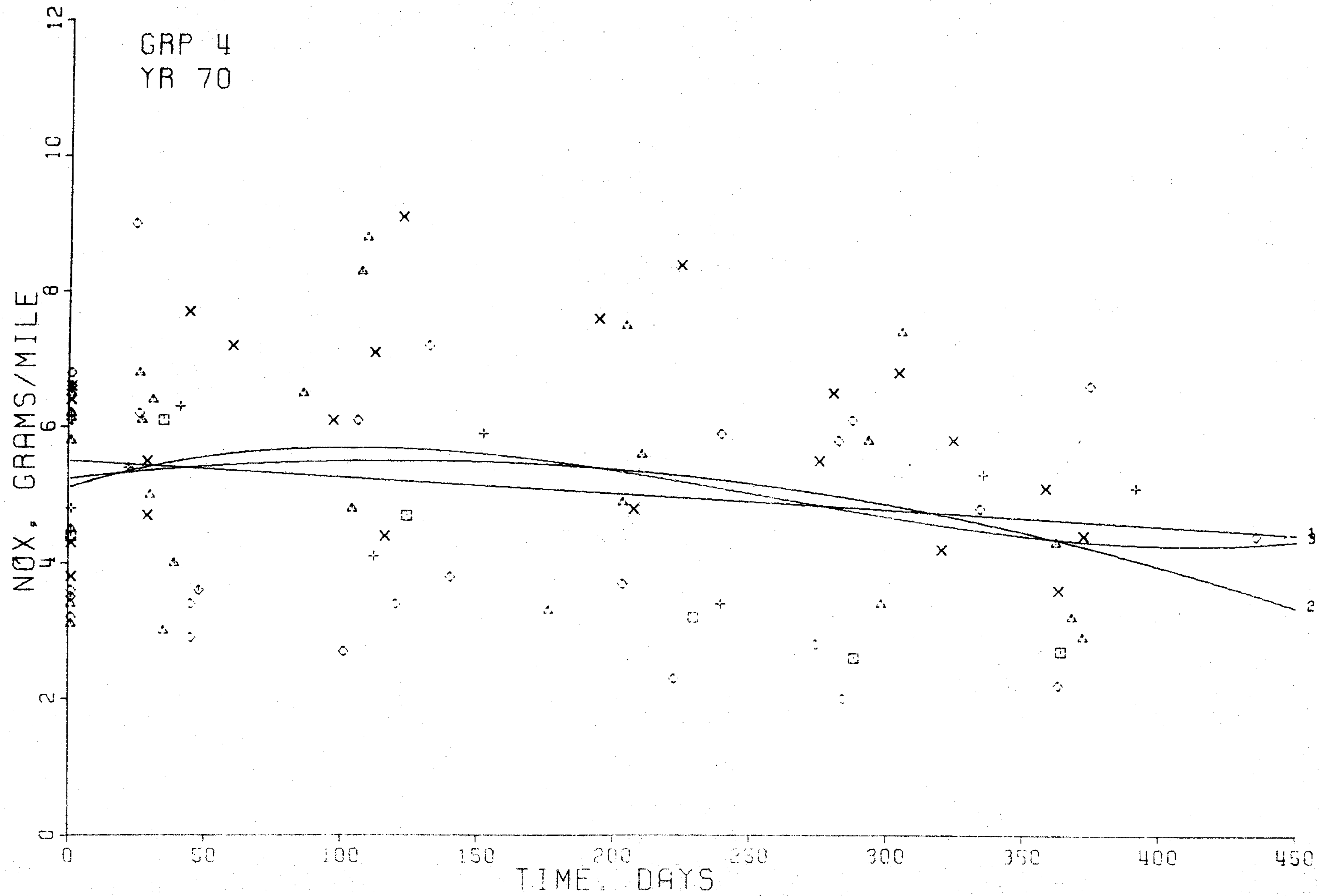


Figure A-116. DEGRADATION VS. MILES



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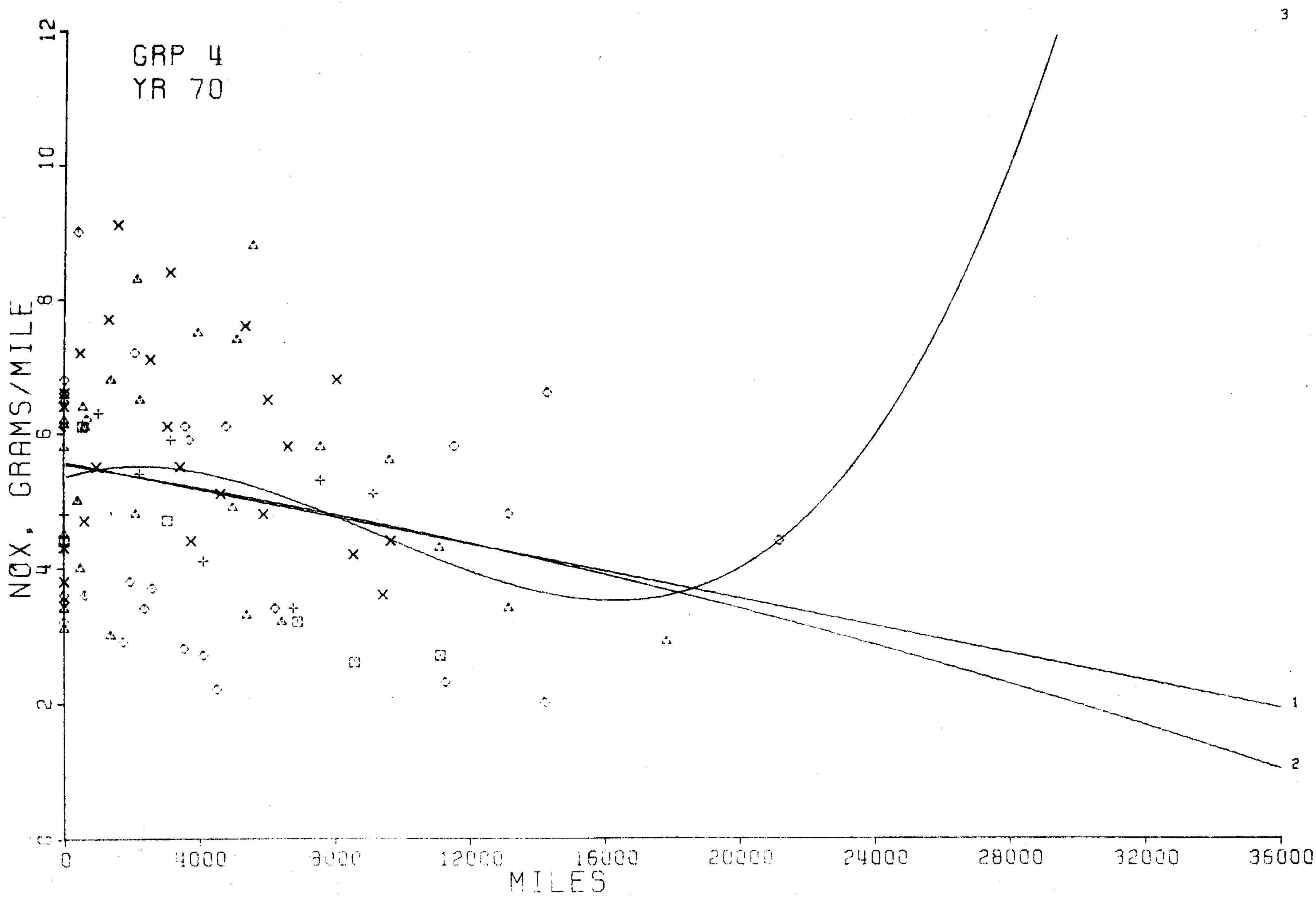


Figure A-118. DEGRADATION VS. MILES

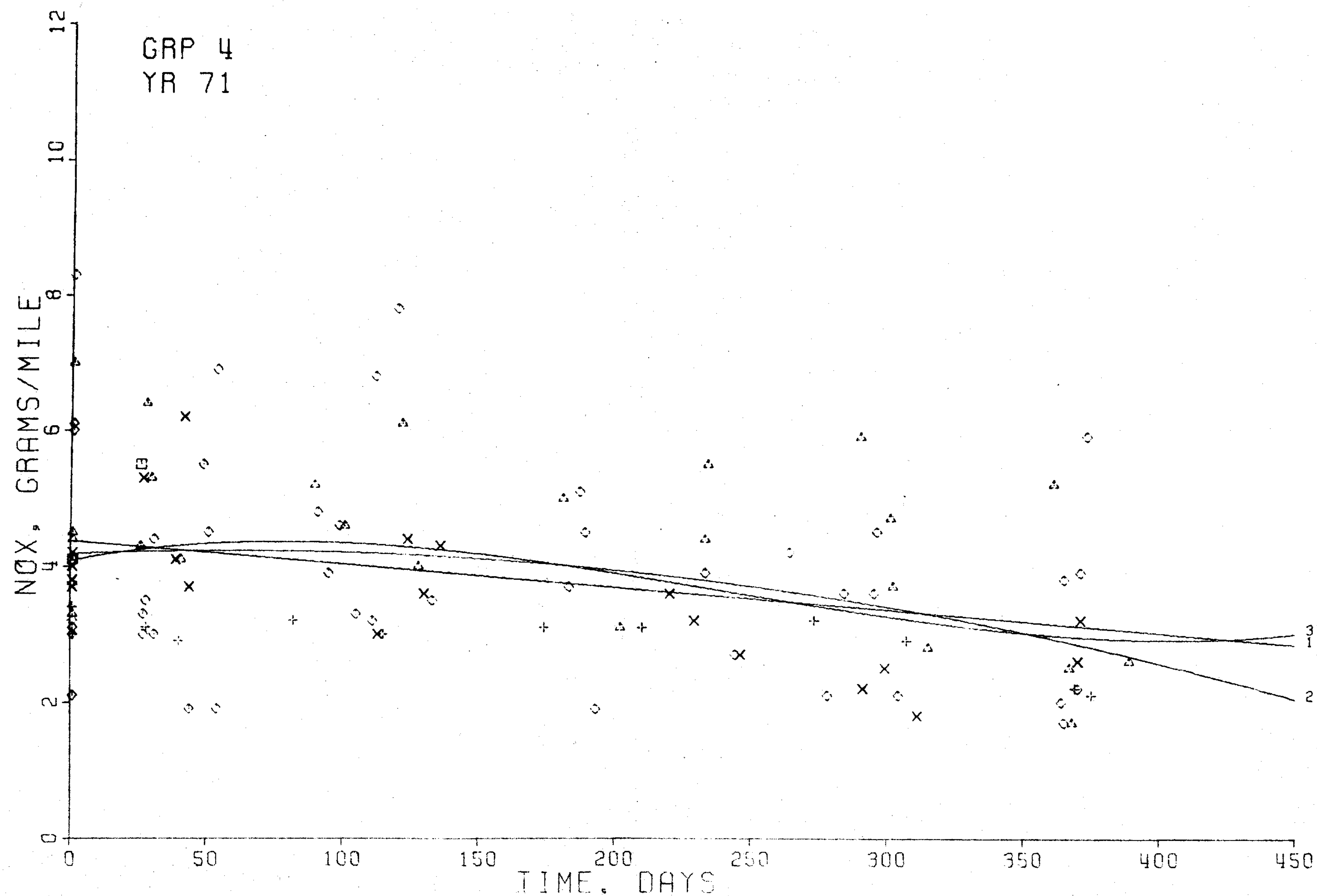


Figure A-119. DEGRADATION VS. TIME

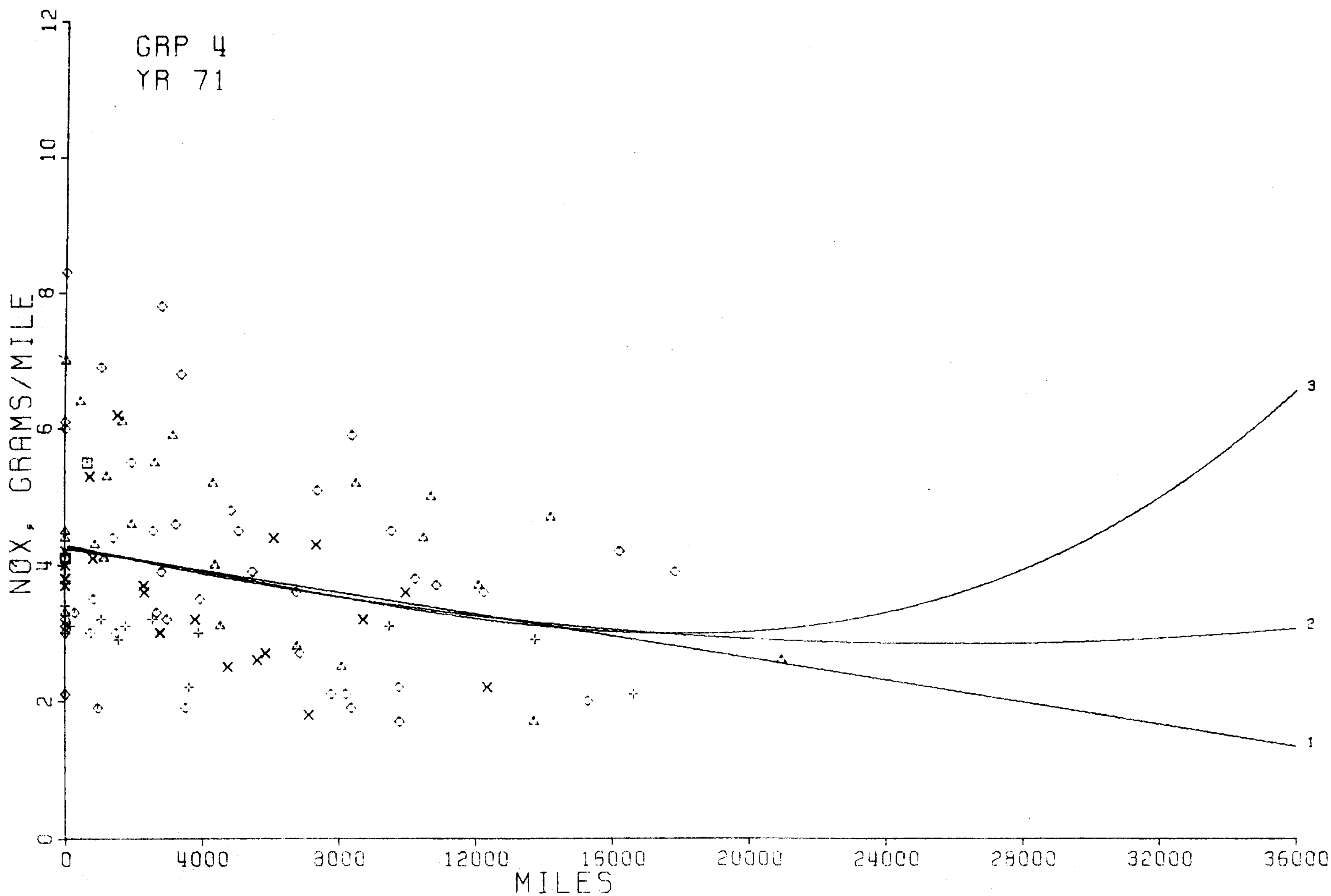


Figure A-120. DEGRADATION VS. MILES

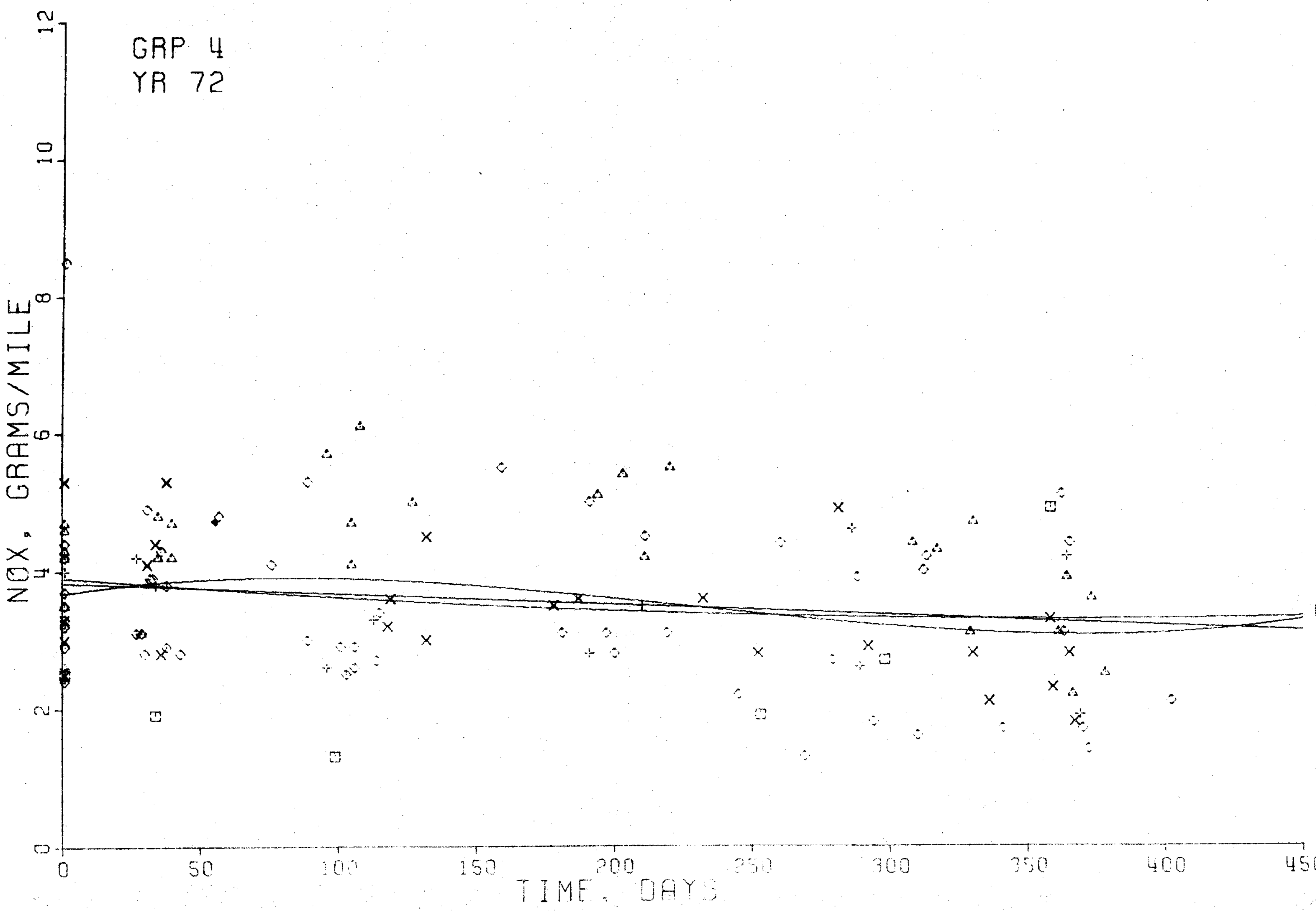


Figure A-121. DEGRADATION VS. TIME

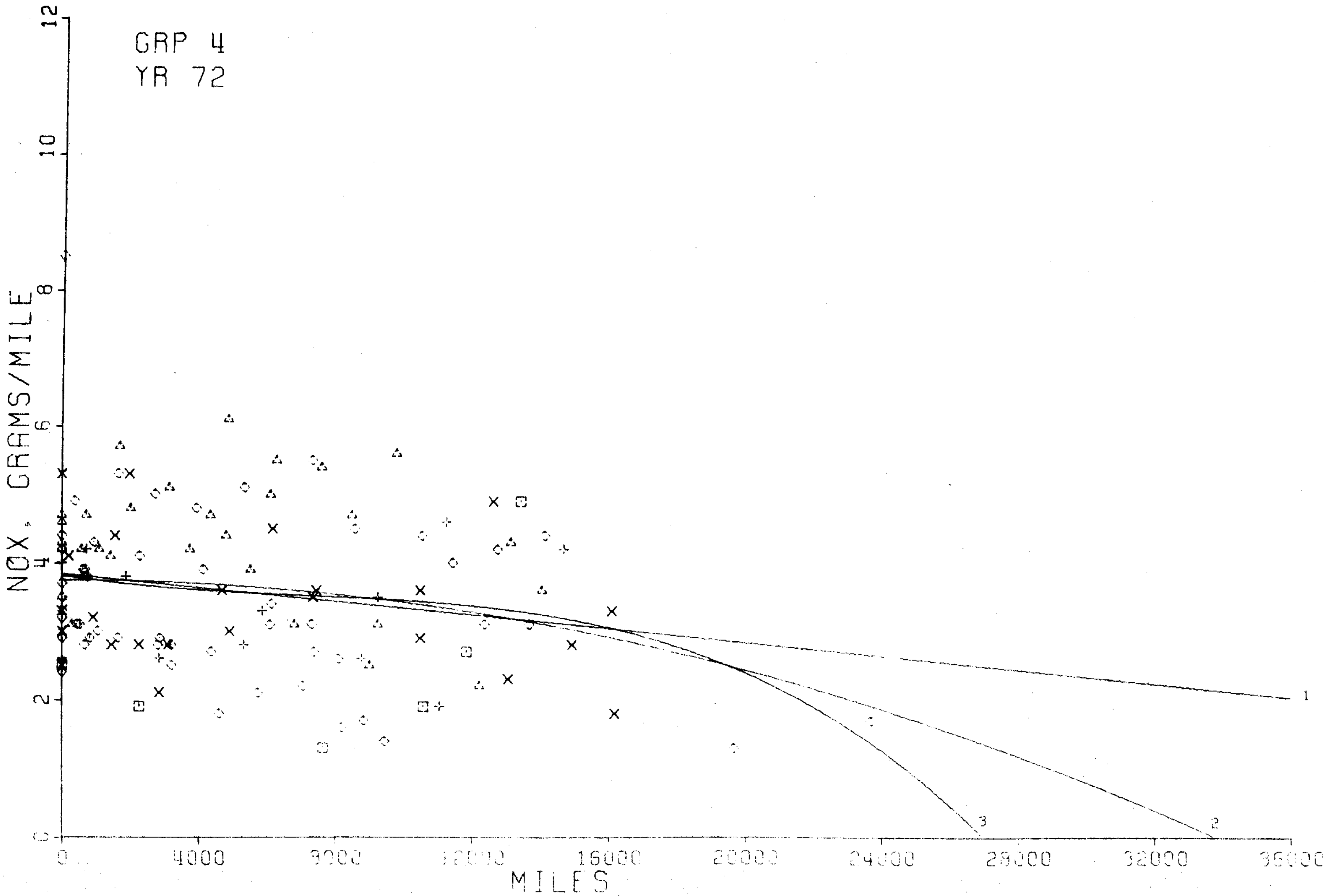


Figure A-122. DEGRADATION VS. MILES

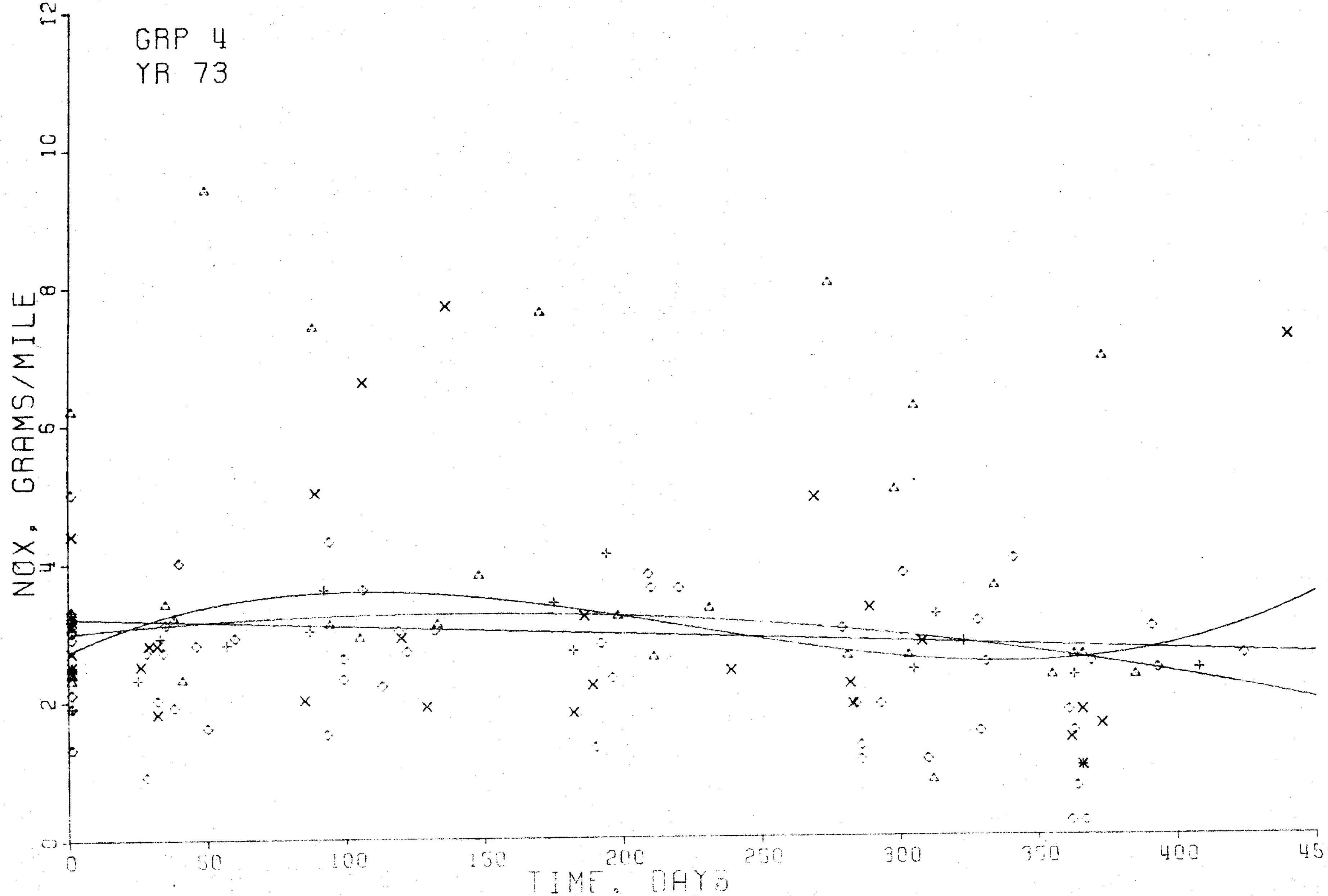
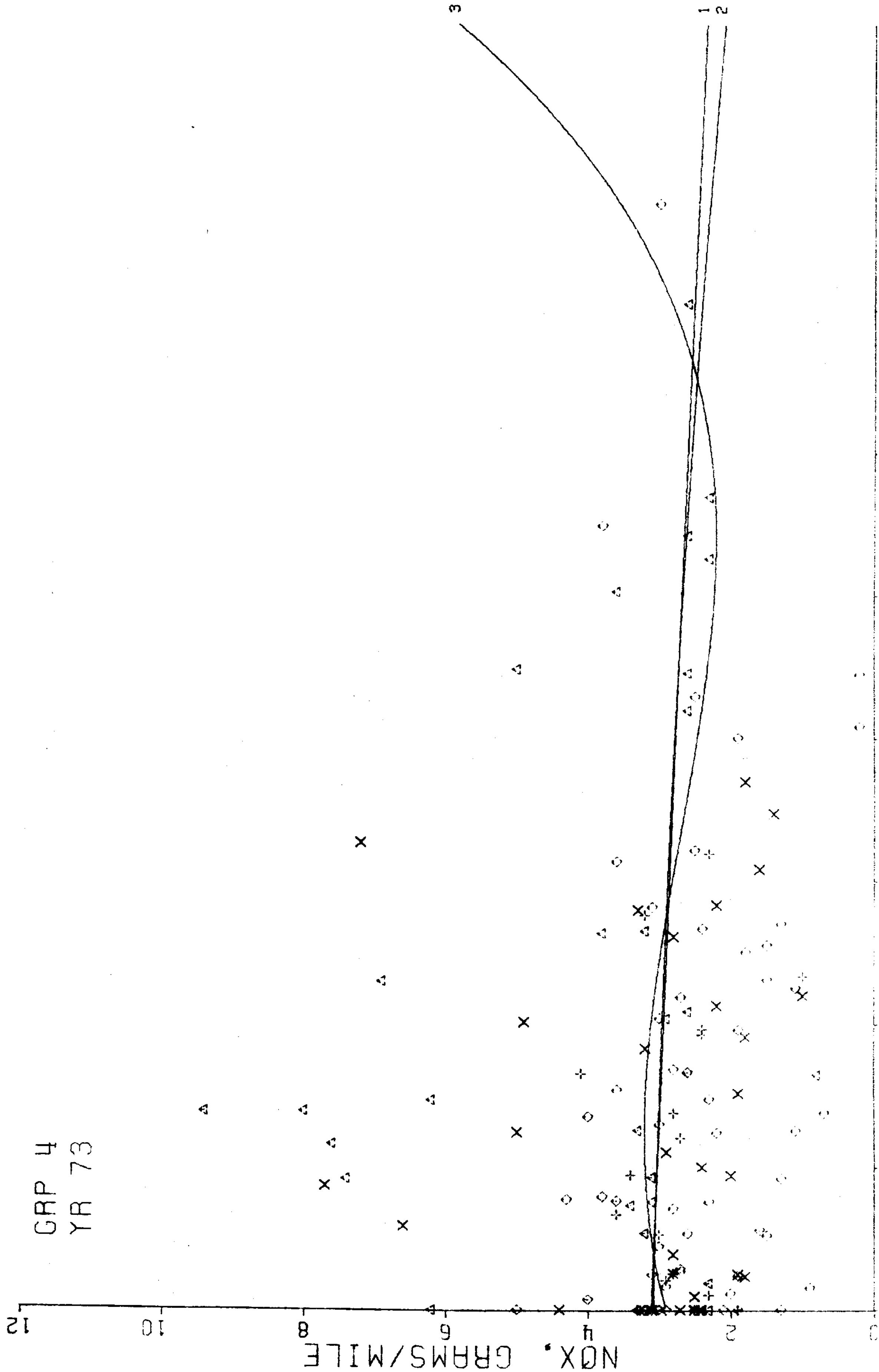


Figure A-123. DEGRADATION VS. TIME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YR 73
NOX, GRAMS/MILE
0
2
4
6
8
10
12
1
2
3

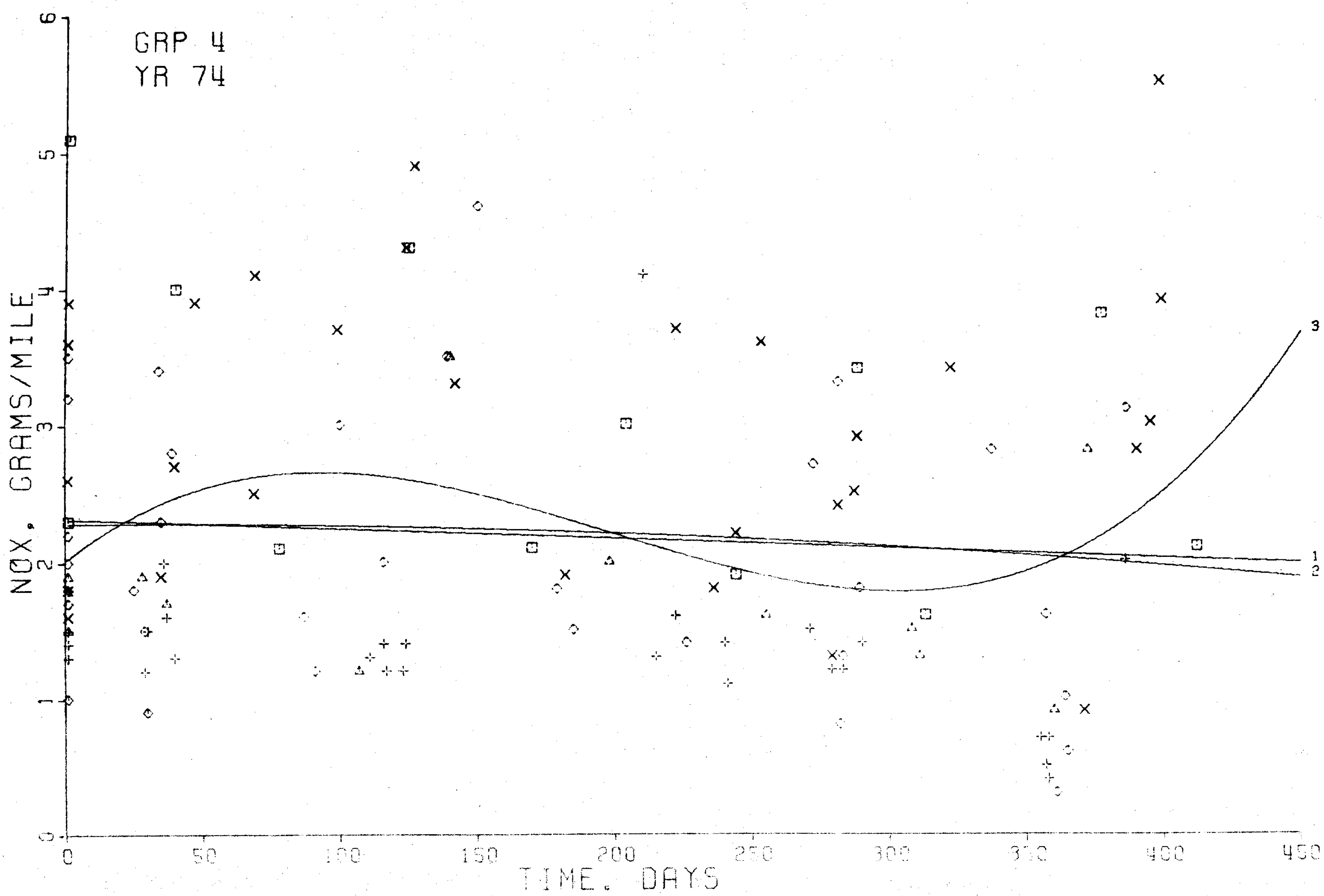

Figure A-125. DEGRADATION VS. TIME

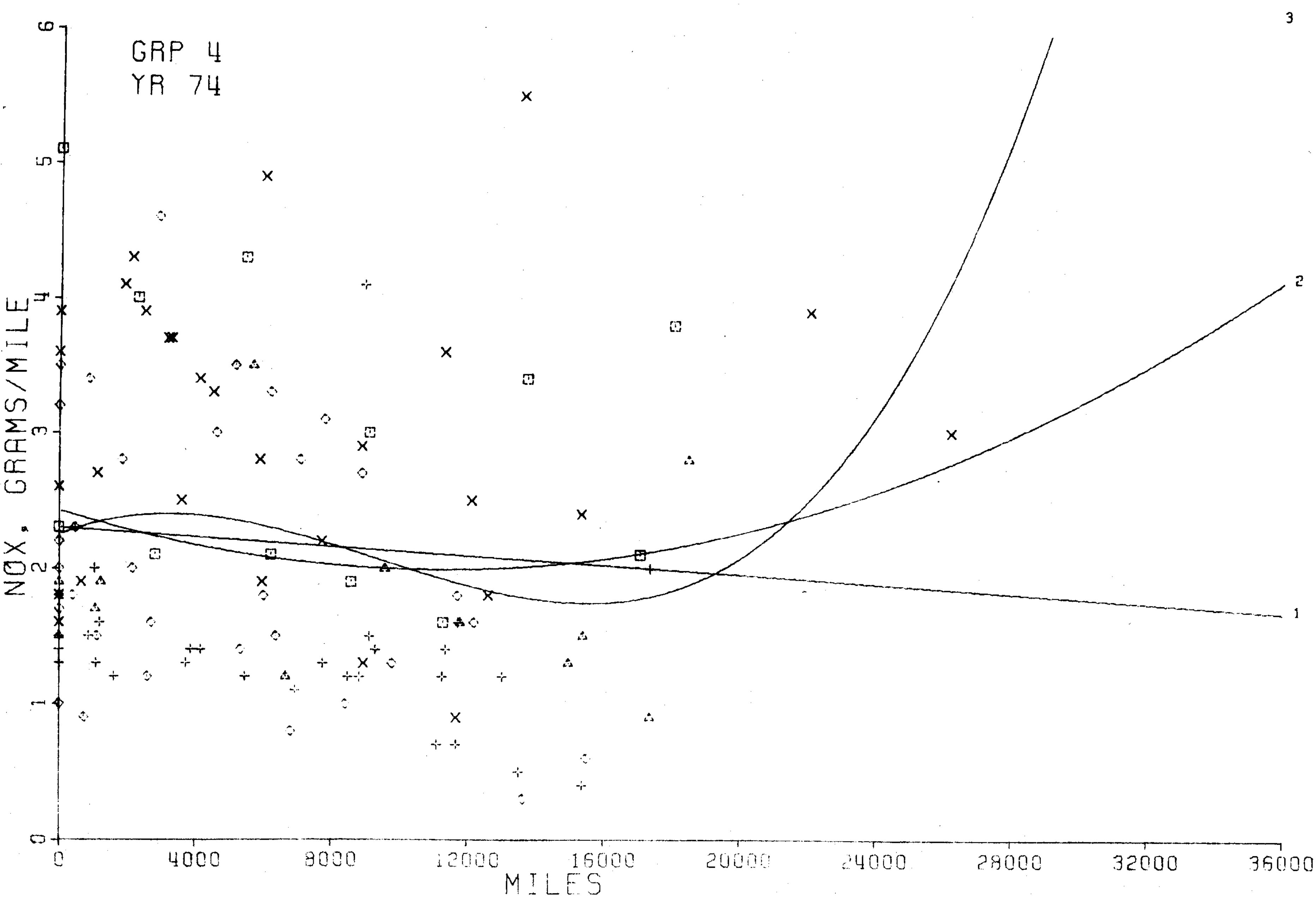

Figure A-126. DEGRADATION VS. MILES